

Appendix A Glossary

Only brief definitions are given to provide a quicklook reference for the reader with regard to terminology. Bold face type within a definition refers to a subject–related entry. ⁶⁷⁹⁸⁾
^{6799) 6800)}

Aberration. Geometrical errors in imagery whereby a perfect image is not formed. Typical aberrations include spherical aberration, astigmatism, coma, and chromatic aberrations. Lens bendings, locations, powers, materials, and increasing the number of lenses and aperture stop positions are all used to minimize aberrations.

The aberration theory of images generated by an optical system has been gradually developed from the seventeenth century on. Early analyses by e.g. Descartes, Roberval and Huygens concern the spherical aberration which arises when imaging an object point through a single refracting or reflecting surface.

Absorption band. A range of wavelengths, or frequencies, in the electromagnetic spectrum within which radiant energy is absorbed by a substance (gas, liquid or solid). In the gaseous phase, absorption lines are much narrower than in liquids or solids. In a polyatomic gas, an absorption band is actually composed of discrete absorption lines which appear to overlap. Each line is associated with a particular mode of vibration and rotation induced in a gas molecule by incident radiation. Examples:

- Ozone (O₃) has several absorption bands. They are: a) the Hartley bands (2000–3000 Å in UV with max absorption at 2550 Å); b) the Huggins bands (weak absorption between 3200–3600 Å); c) the Chappuis bands (weak and diffuse at 4500 Å and at 6500 Å in VIS); d) IR bands at 4.7, 9.6, and 14.1 μm.
- Molecular oxygen (O₂) also has several absorption bands. They are: a) Hopefield bands (between 670 and 1000 Å in UV); b) diffuse between 1019 and 1300 Å (UV); c) the Schumann–Runge continuum (between 1350–1760 Å); d) Schumann–Runge bands (between 1760 – 1926 Å); e) the Herzberg bands (between 2400–2600 Å); f) the atmospheric bands (between 5380–7710 Å, VIS); g) IR at about 1 μm (=10⁴ Å).

Absorptivity. Ratio of the absorbed to the incident electromagnetic radiation on a surface.

Accuracy. Refers to an estimate of how well a certain parameter or measurement is known; it is a measure of the absolute truth of a measurement requiring absolute (traceable) standards. Accuracy is a quality that characterizes the ability of a measuring instrument to give indications equivalent to the ‘true value’ of the quantity measured. The quantitative expression of accuracy may also be given in terms of uncertainty. The actual or ‘true value’ of a quantity cannot be determined; it can only be said to exist within tolerance limits of a measured value. The measurement error is the algebraic difference between the measured (or indicated) value and the true value. Hence, accuracy is by its very nature only an estimation of the true value, taking into account all aspects of measurement.

Acid rain. Rain that is more acid than normal because the raindrops contain dissolved acid gases and/or dust particles (aerosols) from the atmosphere. The principal gases responsible for increased acidity are oxides of sulfur and nitrogen. Generally, rain with a pH below 4.5 is considered environmentally harmful.

Actinometer. A generic term for any instrument used to measure the intensity of radiant energy, in particular that of the sun.

⁶⁷⁹⁸⁾ Portions of this glossary are taken from: “Glossary and list of Acronyms/Abbreviations,” Earth Observation System (EOS), July 1992, Courtesy of EOS Project Science Office (V. V. Salomonson), GSFC, Greenbelt, MD.

⁶⁷⁹⁹⁾ Jeanne Hopkins, “Glossary of Astronomy and Astrophysics,” The University of Chicago Press, Second Edition, 1985

⁶⁸⁰⁰⁾ R. J. Gurney, J. L. Foster, C. I. Parkinson (editors), “Atlas of satellite observations related to global change,” Cambridge University Press, 1993

Active sensor. A sensor having its own source of EMR (Electromagnetic Radiation); it transmits a series of signals to the target and detects the echo. Information is obtained by transmission and reception of radio waves (or light waves). A SAR instrument, a lidar, a radar altimeter, a scatterometer and cloud profile radars – are examples of active sensors.

Actuators. Refer to a class of onboard devices or techniques (manipulators) that are being used in support of a great variety of functions. Some examples are:

- Actuators in the field of attitude control: reaction wheels, momentum wheels, magnetorquer coil/rods, permanent magnets, gravity–gradient boom, nutation damper, control moment gyros, cold gas thrusters, solid thrusters, ion thrusters, mono– or bi–propellant engine, etc.
- Deployment and release mechanisms such as antenna and instrument deployment, positioners, aperture opening and closing devices
- Actuators are being used for autonomous sample acquisition, autonomous instrument placement, robotic arms, rovers, etc.
- Starting with the 1990s, miniature actuators (demonstrators) are being introduced. Piezoelectric actuators⁶⁸⁰¹ (ultrasonic rotary motors) offer special characteristics that are of interest for a number of applications, for instance:⁶⁸⁰² ⁶⁸⁰³
 - Non–powered holding torque in the same range as the maximum driving torque (hard brake without backlash)
 - High positioning accuracy (micropositioning) in direct drive mode
 - Feasibility of non–magnetic motor designs

The simplest actuators are direct piezoelectric actuators (DPA) which can produce displacements of the order of ten to one hundred microns and exhibit high stiffness. These actuators are robust when highly pre–stressed and may be used in active satellite structures without the need for a locking mechanism during launch. – The number of applications of piezoelectric actuators in instruments flown in space is growing, in particular with regard to:

- Precise pointing of optics (adaptive optics)
- Active damping of vibrations
- Small (mass, volume, power) CMGs (Control Moment Gyroscopes) are being introduced at the start of the 21st century providing the dual function of actuator/sensor in an attitude system of a spacecraft.

Adaptive optics. A technique which tries to compensate for the atmospheric degradation (blurring) of the incoming signal of optical imaging systems. However, the compensations achieved, regardless of method, are never “perfect.” The following approaches are in use:⁶⁸⁰⁴ ⁶⁸⁰⁵

- An on–line adaptive optics system (hardware solution). In this version, the adaptive optics system is capable of compensating for the distortion of electromagnetic radiation as it

6801) Note: The piezoelectric effect was discovered in 1881 when Pierre and Jacques Curie (Pierre Curie: 1859–1906; Nobel prize in physics in 1903 together with Henri Becquerel) observed that quartz crystals generated an electric field when stressed along a primary axis. The term piezoelectric derives from the Greek word “piezein,” meaning to squeeze, and the electricity that results from pressure applied to the quartz crystal.

6802) R. Seiler, M.F. Six, M. Debarnot, R. Le Letty, F. Claeysen, “The Ultrasonic Piezo Drive An Innovative Solution for High–Accuracy Positioning,” Proceedings of AIAA/USU Conference on Small Satellites, Logan, UT, Aug. 12–15, 2002, SSC02–VIII–4

6803) Y. Bar–Cohen, X. Bao, W. Grandiab, “Rotary Ultrasonic Motors Actuated By Traveling Flexural Waves,” Proceedings of the Smart Structures and Materials Symposium, San Diego, CA, March 1–5, 1998, Paper 3329–82

6804) S. R. Restaino, D. M. Payne, “Adaptive Optics on a shoe string,” SPIE Vol. 3494, 1998, pp. 152–160

6805) D. Dayton, S. Browne, J. Gonglewski, “Control Loop Analysis for a Nematic Liquid Crystal Spatial Light Modulator Used in an Adaptive Optics System,” SPIE Vol. 3494, 1998, pp. 161–160–167

passes through the turbulent atmosphere and the optical system. Elements of an adaptive optical system are a high-speed wavefront sensor (sensing the turbulence-induced aberrations), a flexible mirror system whose surface can be electronically controlled to correct for aberrations, and a computer controller that converts the wavefront measurements into deformable mirror commands. — More economic solutions are suggested by the use of LCPM (Liquid Crystal Phase Modulator) to deform the mirror, and by the use of the pupil masking technique.

- A post facto approach (software solution), where the data are acquired by an imaging instrument and processed off-line with suitable iterative algorithms to increase the overall resolution obtained by the optics system. Speckle imaging is an example of such a technique.⁶⁸⁰⁶⁾
- A hybrid approach using an adaptive optics system in combination with post facto processing.

Advection. Refers to a change in property of a moving air parcel from one region to another (say, from a warm region to a cool region, thereby changing its temperature). Commonly, advection is divided into horizontal and vertical components; it differs from convection only in scale. Convection is transport by random thermally induced currents, whereas advection is transport by steady vertical currents.

Aerosol. The term is used to describe many types of small particles in the atmosphere that both absorb and reflect incoming sunlight. Aerosols are a stable suspension of fine (solid or liquid) particles such as dust, smoke particles, water droplets, etc. in the atmosphere. The smallest aerosols are the atoms of the various atmospheric gases. The range of sizes varies from a few nanometers (molecules) to tens of micrometers (wind-driven sand). Some aerosols (sea salt and haze) occur naturally and some (smoke) are man-made (anthropogenic). The ocean is a significant source of natural tropospheric aerosols. Once in the atmosphere, aerosols may be transported away from their place of origin, sometimes over great distances.

Aerosols can directly and indirectly affect the radiation budget of the atmosphere. Their direct radiative effect is due to their scattering, absorption, and emission properties. Their indirect effect is a result of their ability to act as condensation nuclei in the formation of clouds. Both tropospheric and stratospheric aerosols play an important role in global climate change.

Airglow. A nighttime glow from the upper atmosphere, occurring over middle and low altitudes, due to the emission of light from various atoms, molecules, and ions. In particular, the term airglow describes the process of photon emission resulting from the various natural reaction of atomic oxygen with itself or with other constituents of mesopause/lower thermosphere. The intensity of each emission is dependent upon the densities of the reacting species.

Air-mass-zero (AM0), etc. The solar radiation that is available to power a solar cell on the surface of the Earth^{6807) 6808)} is less than that available to power a satellite in orbit above the Earth, due to atmospheric absorption of some of the solar radiation. The available solar radiation is frequently described by giving an air mass value, such as “air mass zero” (AM0), “air mass one” (AM1), “air mass 1.5” (AM1.5), etc.

6806) J. C. Christou, et al., “Physically Constrained Iterative Deconvolution of Adaptive Optics Images,” SPIE Vol. 3494, 1998, pp. 161–175–190, Proceedings of the SPIE EUROPTO Series, Sept. 23–24, 1998, Barcelona, Spain

6807) “Solar, wind, and Fuel Cell Problems, Instrumentation and Measurement in Energy,” ISAT301, 2001

6808) Solar Spectral Irradiance (Air-mass-zero = AM0). In 1999, the American Society for Testing and Materials developed an AM0 reference spectrum (ASTM E-490) for use by the aerospace community. That ASTM E-490 Air-Mass-Zero solar spectral irradiance is based on data from satellites, space shuttle missions, high-altitude aircraft, rocket soundings, ground-based solar telescopes, and modeled spectral irradiance. The integrated spectral irradiance has been made to conform to the value of the solar constant accepted by the space community; which is 1366.1 W/m².

- AM0 refers to the solar radiation available just outside the earth's atmosphere. The corresponding **total solar irradiance is 1353 W/m²**, and this value is called the **solar constant**.⁶⁸⁰⁹⁾
- AM1 refers to the solar radiation available at the earth's surface when the sun is at the zenith (total solar irradiance: 925 W/m²).
- In general, when $x > 1$, AM x is defined to be the solar radiation available at the Earth's surface when the sun is an angle: $\theta = \cos^{-1}(1/AMx)$ from zenith. Rewriting this equation, the air mass value turns out to be: $AMx = (\cos \theta)^{-1}$. θ is the angle between the sun and zenith. The standard spectrum for temperate latitudes is AM 1.5 which corresponds to an angle of 48° from the vertical, equivalent to a solar irradiance of 925 W/m².

Albedo. The Earth's albedo is a measure of how much incident radiation is reflected (hence, it is the ratio of the upwelling to down-welling radiative flux at the surface). The greater the albedo, the greater the amount of light reflected. This value ranges from 0 to 1, with 1 being perfect reflectivity and 0 being a completely black surface. The Earth has an average albedo of around 0.4. — Measured albedo information may be applied to cloud analysis, it may also serve in calculations of inherent contrast between targets and background. By definition, white surfaces (i.e. an all reflective Lambert surface) have albedos close to 1 (snow and ice), black surfaces have albedos close to zero. The lower the albedo, the more energy from the sun is absorbed.

Changes in Earth's surfaces can therefore affect how much of the Sun's energy is absorbed — such as a decrease in snow cover or an increase in the area used for agriculture. If the amount of energy absorbed changes, this has an effect on Earth's energy budget and ultimately affects our weather and climate.

Aliasing. A term in data processing referring to two or more distinctly different signals having identical sample values.

Along-track repeat altimetry: Along-track repeat altimetry consist in considering every single point of measurement along the satellite track and computing the time series of each of these individual points over ocean surfaces. The orbit of satellite altimeters in repeat mode is constrained to fit within a limited range of cross-track repeat position.

For example, the ERS mission in a 35 day repeat mode is constrained to be in a ± 1 km of the nominal track. This implies that if one plots the repeat track nadir positions, a distribution of measurements in a 2 km wide band is obtained. This size is similar in size to the first impact of the radar altimeter echo. Thus, over the ocean, most studies consider it an exact repeat pass, not affected by cross-track variations in topography, which are negligible.

Although repeat-track altimetry is less accurate than the crossover altimetry method, due to uncertainties introduced through the need to correct for cross-track slope variations, it offers the advantage of providing more densely sampled observations between satellite orbit crossing points.

Amplitude modulation (AM). The baseband signal is caused to vary the amplitude of the carrier wave to create the wanted information content.

Analog data. Data represented in continuous form, as contrasted with digital data having discrete values.

Ångström (Å, after A. J. Ångström, a Swedish physicist). Refers to a unit of length used in the measurement of short wavelengths (X-rays, gamma rays, etc.) and in the measurement of molecular and atomic diameters. $1 \text{ Å} = 10^{-10} \text{ m}$ or $10^{-4} \mu\text{m}$.

Anamorphic effects in an imaging system are distorting effects that may occur at various interfaces in the optical path such as: in a dispersive grating (diffraction errors); in an image

⁶⁸⁰⁹⁾ <http://tredc.nrel.gov/solar/standards/am0/newam0.html>

slicing system (which makes optimum use of the detector surface with minimal dead space and provides continuous mapping of each slice onto the detector), the sampling may be accomplished via anamorphic magnification in the instrument fore–optics; in situations where intensity variations parallel to the limb distort the interferogram, the spatial information in this dimension can be washed out by using an anamorphic telescope. – An anamorphic imaging system design (imaging spectrometer, imaging interferometer or a spectroradiometer) performs all these various optical corrections.

Example: The design difficulty is that an off–axis Fourier optical system (of an interferometer) must be made anamorphic to generate an image perpendicular to the interferogram pupil plane.

Antenna. Antennas and radio–wave propagation involve key technologies for space communications, navigation and remote sensing, for all terrestrial wireless transmission systems, for radar, and for a number of other applications ranging from mine detection to biological wave interactions and medical electromagnetics.

An antenna is a sender and receiver system of electromagnetic radiation (in remote sensing terminology the antenna may be part of the sensing instrument, or may be regarded as a coupling device between the target and the sensing instrument). The term antenna refers a) to that part of a transmitting system that converts electrical energy to electromagnetic waves; and conversely b) to that part of a receiving system that converts electromagnetic waves to electrical energy (current) in the receiver (a duplexer automatically switches the antenna from a transmitting function into a receiving function). Physically, an antenna consists of metal surfaces that provide conducting paths for oscillating electric currents and charges. The radiated power of an antenna depends on the shape and size of its geometric contour and on the amplitude and frequency of its oscillation. Some antenna designs:

- **Dielectric rod antenna.** An antenna consisting of a dielectric cylinder that is partially inside a circular waveguide (pipe). It is possible to have an electric field applied to this device – no currents flow through it – although energy passes from one end to the other, thereby generating electromagnetic waves.
- **Dipole antenna.** A thin metal cylinder or wire excited by an alternating current generator at its center so that the ends are oppositely charged. – A dipole antenna is a form of open circuit in which the current oscillates between the ends of the conductor. A dipole antenna may also be a type of array consisting of a system of dipoles. A dipole antenna differs from a dish antenna in that it consists of many separate antennas that collect energy by feeding all their weak individual signals into one common receiving set.
- **Helix antenna.** A helical wire wound with a circumference of about one wavelength and a pitch of 1/4 wavelength over a ground plane with a 1 wavelength minimum diameter.
- **Lens antenna.** Several types are in use: a) dielectric lens – the aperture of the antenna is equal to the projection of the rim shape; b) artificial dielectrics; c) strip antenna – metal strips are used as waveguides to increase the phase velocity by acting as parallel–plate waveguides.
- **Loop antenna.** The current circulates around or oscillates within the closed loop. The most important application of the loop antenna is reception. The shielded loop antenna is useful as a probe for measuring the magnetic field.
- **Microstrip patch antenna.** A printed circuit antenna consisting of a radiating patch supported by a dielectric layer over a ground plane.
- **Monopole antenna.** A thin metal cylinder or wire erected vertically over a conducting plane and excited by an alternating current generator connected between the base of the cylinder and the conducting plane.
- **Pencil beam antenna.** An antenna whose radiation pattern consists of a single main lobe with narrow principal plane beamwidths and sidelobes having relatively low levels.

- **Phased–array antenna.** Phased arrays are antenna systems composed of radiating array elements and a network that distributes the signals and adjusts the element gain and phase. For an active phased array, each antenna element is composed of a radiator and a T/R (Transmit/Receive) module which contains the gain and phase adjustment. Active phased arrays often allow corrections to be made to the weights by commanding different gain and phase settings.

Phased arrays are inherently random–access devices consisting of multiple antenna elements (fixed dipoles) which are fed coherently and use variable phase– or time–delay control at each element to scan a beam to given angles. Arrays are sometimes used in place of fixed aperture antennas (e.g. reflectors or lenses) because the array arrangement allows more precise control of the radiation pattern (lower sidelobes). The primary reason for using phased arrays is to produce a directive beam that can be scanned (repositioned) electronically in two dimensions without any mechanical movement (see also **Phased–array Technology**).

- **Stick antenna.** Also referred to as a fan–beam antenna, it produces a major lobe whose transverse cross section has a large ratio of major to minor dimensions.
- **Slot antenna.** A slot in a metal sheet with dimensions $\lambda/2$ in length and width w ($w \ll \lambda$) provides a means for achieving efficient directional energy radiation and reception. The radiation leaving the slot antenna is polarized in the direction normal to the major slot dimension (if the slot is horizontal, then the polarization is vertical, and vice versa). Array arrangements of slots permit the radiation of higher energies and consequently the illumination of larger target areas.

Antenna reflectors. A reflector antenna is a large–aperture (gain) directional antenna. A parabolic reflector (mirror) has the property of transforming rays emerging radially from a point source at its focus into a bundle of parallel rays. The reflected parallel rays are all in phase in any plane perpendicular to the axis of the parabola. The laws of optics apply with respect to the radiation geometries and projections (focusing, bundling, redirection of energy, diffraction effects, etc.). Characteristic parameters of a reflector antenna are a function of the properties of the feed and the ratio of the reflector’s focal length (F) to the diameter (d) of its circular aperture.

Reflector antennas are widely used in the microwave range of the electromagnetic spectrum in the fields of remote sensing, telecommunication, and radio astronomy. Reflectors are inherently broadband instruments; the bandwidth and polarization are determined by the feed antenna. Reflector examples: paraboloidal, parabolic cylinder, dual (Cassegrain, Gregorian), offset–fed, corner, dichroic.

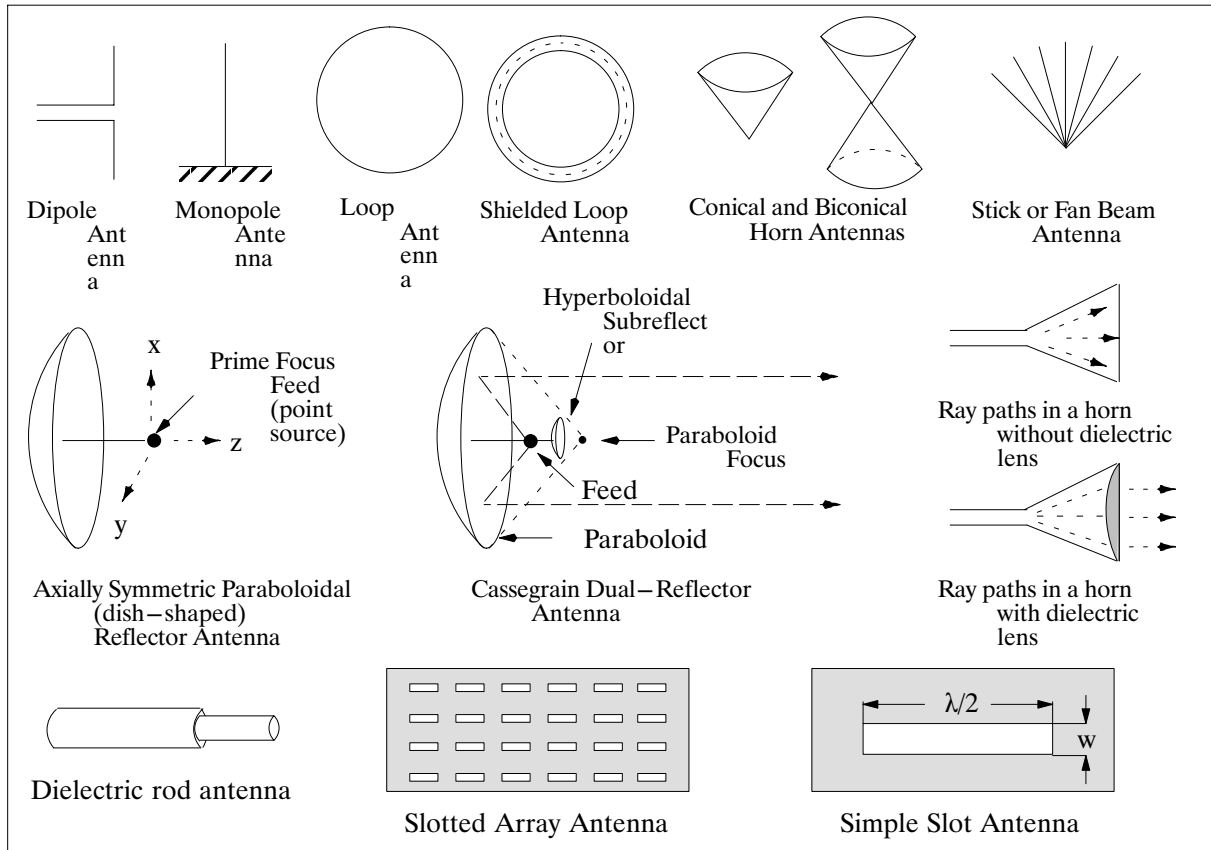


Figure 1568: Some antenna geometries

- **Cassegrain dual–reflector antenna (telescope).** Guillaume Cassegrain, a French scientist, proposed the design in 1672. The basic properties of the Cassegrain dual–reflector are determined from the principles of ray optics. A small convex hyperboloidal subreflector is placed between the point source feed and the prime focus of the parabolic dish. Rays from the feed are transformed by the subreflector into rays that appear to be emerging from the paraboloid focus. The rays reflect from the parabolic reflector parallel to its axis.
- **Offset aperture reflectors.** The blocking of portions of the aperture of a reflector antenna by its feed, supporting structures, or by the subreflector generally degrades the radiation distribution. Hence, high–performance systems employ offset–fed antennas to eliminate the effects of aperture blocking.
- **Horn antenna.** A horn is an aperture antenna fed from a waveguide mode in an expanded waveguide. The bandwidth is determined by the feed waveguide. Corrugated horns are widely used as feeds for reflectors and as direct radiators in applications that include radiometers.
- **Dichroic reflector.** The term dichroic (chros = color in Greek) implies selective absorption in crystals of electromagnetic radiation vibrating in different planes. – Refers to frequency–selective surfaces designed to exhibit different ratio–frequency properties. In its simplest form, a dichroic surface is virtually perfectly reflecting at one frequency and virtually transparent at another. The most common application of dichroic reflectors has been as subreflectors in Cassegrain antenna systems. Besides reflectors the dichroic principle is also applied to beamsplitters and filters.
- **Antenna retroreflector.** Retroreflection is defined as radiation that is returned in angular directions which are very close to those angular directions from which it came. This (incoming/outgoing) property is maintained over wide variations of the incident radiation. Retroreflector devices come in a variety of forms and have many uses. In remote sensing, a

retroreflector uses total internal reflection from three mutually perpendicular surfaces. This kind of retroreflector is usually called a ‘corner cube retroreflector’. A corner cube reflector is normally used for radar measurements having a known radar cross section.

- **Antenna reflectarrays.** Generally, three types of reflectarray configurations can be distinguished: passive (fixed beam and passive reflection), semi–active (electronic beamsteering and passive reflection) and active (electronic beamsteering and amplified reflection).

Antenna RF prism concept (RF lens). At the start of the 21st century, RF prism is a new space antenna concept where an array (active array antenna) is fed through a mesh of points on the antenna back face with RF signals transmitted (or received) by another satellite, called illuminator and flying on the same orbit. The RF prism concept opens up a new approach to large space antennas – resulting from the satellite system configuration. The concept can be applied in remote sensing missions requiring a large antenna. Moreover, in passive imagery application, VLBI techniques may be used to restrain the antenna size requirement to a single dimension.⁶⁸¹⁰⁾

Antenna aperture. Surface area (size) of a reflector or horn that is illuminated by the outgoing and/or incoming radiation.

Antenna bandwidth. Range of frequencies within which the performance of an antenna, with respect to some characteristic, conforms to a specified standard. There are many different types of bandwidths, including gain, VSWR (Voltage Standing Wave Ratio), and polarization. For example, a typical bandwidth specification might be: The antenna gain with isotropic must be $> 10 \text{ dB} \pm 10 \text{ MHz}$ from a center frequency of 2090.0 MHz.

Antenna beamwidth. A planar cut through the radiation pattern containing the direction of the maximum of a lobe, the angle between the two directions in which the radiation intensity is one–half the maximum value and one tenth the maximum value, or in which zero is defined to be the half–power (3 dB), tenth–power (10 dB), or null beamwidth.

Antenna depression angle. The angle between the local horizontal and the center line of the antenna beam pointing at the target.

Antenna directivity. Directivity is a measure of the concentration of radiation in the direction of the maximum. It is the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions.

Antenna feed. The device in an antenna system that transmits or receives energy to or from the antenna aperture and the radio system.

Antenna footprint. Instantaneous projection of a directional antenna beam illumination on a surface.

Antenna gain. Ratio of the transmitted radiation intensity in a given direction to the radiation intensity that would be received if the power accepted by the antenna were radiated isotropically. In this context, ‘peak antenna gain’ refers to the maximum radiated intensity expressed as a ratio to the radiation power intensity of a hypothetical isotropic antenna fed with the same transmitting power.

Antenna – intermediate frequency (IF). In microwave systems, a frequency that is common to all channels at which amplification takes place, interconnections are made, and/or automatic gain is adjusted.

Antenna – isotropic. A theoretical antenna of infinitesimal size in which it is assumed that all of the energy is radiated (point source). This concept serves as a reference basis for other antennas of finite dimensions.

6810) J.–P. Aguttes, H. Bentsen, G. Caille, “The RF Prism concept: A RF lens and its illuminator(s) on separated satellites for enabling very large antennas,” Proceedings International Symposium Formation Flying, Oct. 29–31, 2002, Toulouse, France

Antenna noise temperature. Refers to the increase of the receiver input noise temperature of an antenna system.

Antenna polarization. Spatial orientation of the electric/magnetic field radiated by an antenna. The vector electric/magnetic fields of free space traveling waves are perpendicular to the direction of travel. Polarization describes how fields behave in time and space. For example, a “circularly polarized” wave can be thought of as having the electric field rotating about the direction of travel. The direction of the field rotates one turn per period of the wave. A “linearly polarized” wave radiated from an antenna into a specific direction has the electric field direction fixed with time – the only variations are in the instantaneous magnitudes of the electric/magnetic fields.

Antenna scanning techniques.⁶⁸¹¹⁾ For SAR observations the antenna beam casts an elliptical footprint on the ground with an effective rectangular aperture antenna of typical size 10 m (along-track) and 3 m (across track).

- **Electronic scanning.** Defines a method of positioning an electromagnetic beam in space or scanning across a target surface by electronic means. The antenna aperture remains fixed; no mechanical mechanism is involved in the scanning process.
 - Phase scanning (moved the beam by controlling the phase of the antenna illumination, using phase shifters or delay lines – see also **Phased-array technology**)
 - Frequency scanning (moves the beam by changing the carrier frequency of the transmitter and receiver)
 - Electronic feed switching
- **Mechanical scanning.** Defines a method of positioning an electromagnetic beam in space by mechanical rotation or angular positioning of the radiating aperture of the antenna system.
- **Electronic/mechanical scanning.** A hybrid method that employs electronic scanning in one dimension, say in elevation, and mechanical scanning in azimuth.

Antenna sidelobes. Undesired directions in which a directive antenna also receives or radiates power. Sidelobes are generally much weaker than the main beam in the desired direction.

Antenna waveguide. Usually a hollow metal structure (pipe or other profile) intended to guide or to conduct along its path an electromagnetic wave in a given microwave range (a waveguide is usually attached to a horn; it may also directly serve as a feed for a reflector). The internal dimensions of a waveguide are related to the transmission efficiency of specific frequencies. The cutoff frequency refers to that frequency below which a particular waveguide cannot satisfactorily transmit the wave.

Antenna waveguide modes. Refer to the wave propagation distribution patterns that may exist within a waveguide. They depend on the shape and size of the waveguide with respect to the length of the wave traversing the guide. Each mode has a specific topology, velocity, and energy distribution along and across the guide cross section. The cross section of the waveguide may be square, rectangular, circular, or elliptical.

Anthropogenic gases. ‘Human-induced’ gases emitted into the atmosphere and interacting with the environment. In a wider sense the term refers to all gases emitted as a result of human activities (e.g., chlorofluorocarbons from technical combustion processes, carbon dioxide and methane from livestock farms, rice paddies, biomass burning, etc.).

Aperture. Refers to the maximum diameter of a radiation beam that can pass through a system (either an optical lens or mirror system or an antenna system) on a telescope or satel-

⁶⁸¹¹⁾ P. J. Kahrilas, “Electronic Scanning Radar Systems, Design and Architecture,” in ‘Practical Phased-Array Antenna Systems,’ E. Brookner, Editor, Artech House, Boston, MA

lite. The radiation—gathering power of such a system is proportional to the square of the diameter (or aperture) of the lens (mirror or antenna). Hence, sensors with wider apertures are able to capture more information. Apertures are used to restrict the field of view (FOV) of the responsive element (such as a detector). This is often done to reduce noise (cooled detectors are photon—noise limited) from extraneous sources.

Aperture (distributed aperture). A distributed aperture refers to a collection of sensor configurations with relatively fixed positions, operating and observing in a collaborative way. Examples: 1) An array of bore—mounted cameras (at some distance apart) represents a simple distributed aperture. 2) An array of radiometers, mounted in Y—shape (like the SMOS instrument) and representing a 2—D configuration, is also a distributed aperture. 3) The formation flight of several spacecraft forms also a distributed aperture. The “sensor configuration” represents in this case a collection of optical (or of microwave) elements on individual spacecraft. These so—called advanced arrangements of distributed aperture create much larger distributed apertures (than fixed arrangements on a single S/C) thereby eliminating the conventional restriction of “physical structure.”

Aperture stop. Location within a lens system where the principle ray passes through and crosses the optical axis. The presence of a mechanical limiting aperture (hole, slot, etc.) typically creates a limiting size.

Aperture synthesis. A technique (pioneered in radio astronomy) of generating high spatial resolution images by dividing the collection area of a telescope (or antenna) into smaller apertures spread out in a pattern covering several baselines (distributed aperture). In microwave radiometry the concept employs an interferometric technique in which the product from antenna pairs is sampled as a function of pair spacing. Substantial reductions in the antenna aperture needed for a given spatial resolution can be achieved with this technique. However, the performance leap in resolution must be paid for with higher requirements for instrument precision sensing and stabilization. ESTAR (R.88) and MIRAS (R.138) are examples of airborne synthetic aperture microwave radiometers (both instruments operate in L—band).

Apodizing/unapodizing.⁶⁸¹²⁾ The terms are used in the context of data processing in a FTS (Fourier Transform Spectrometer). The actual lineshape of a FTS interferogram is close to $(\sin x)/x$, which is a function with intense side—lobes (also referred to as “feet”). This is the shape that the spectrum of an intrinsically sharp line (e.g. a laser line) would have if the spectrum were untreated, or “unapodized”; to apodize means literally (Greek) “to cut off the feet”. Apodizing consists of treating the spectrum to reduce the sidelobes at the expense of degraded resolution (usually by a factor of about two). Apodizing can be done either by tapering the interferogram prior to transforming, or by algebraically filtering the spectrum after transforming.⁶⁸¹³⁾

Area Array Camera. Refers to a solid—state imaging device (CCD technology) with an array (rows and columns) of pixels producing a 2—D image. The Area Array Camera is also referred to as Matrix Array Camera.

Astigmatism. Refers to an aberration in which the light in one plane (for instance the plane of the paper) focuses at a different location from light in the orthogonal plane.

6812) Typical sources observed by a spaceborne or airborne FTS are extended such that (due to FOV) the rays through the interferometer are not collimated, leading to side lobes.

6813) Courtesy of K. C. Chance of the Harvard—Smithsonian Astrophysical Observatory, Cambridge MA

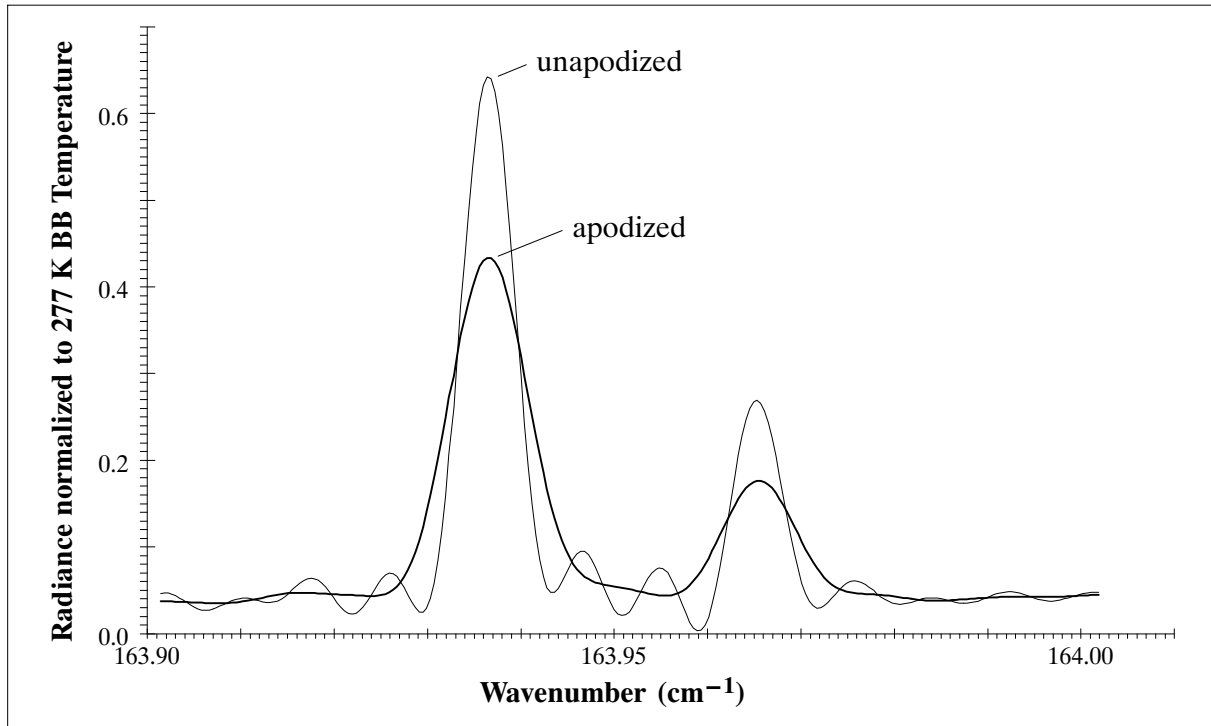


Figure 1569: Sample illustration of an apodized and an unapodized radiation curve

Atmosphere. The envelope of gases surrounding the Earth and bound to it by the Earth's gravitational attraction. Studies of the chemical and radiative properties, dynamic motions, and physical processes of the Earth–atmosphere system constitute the field of meteorology.

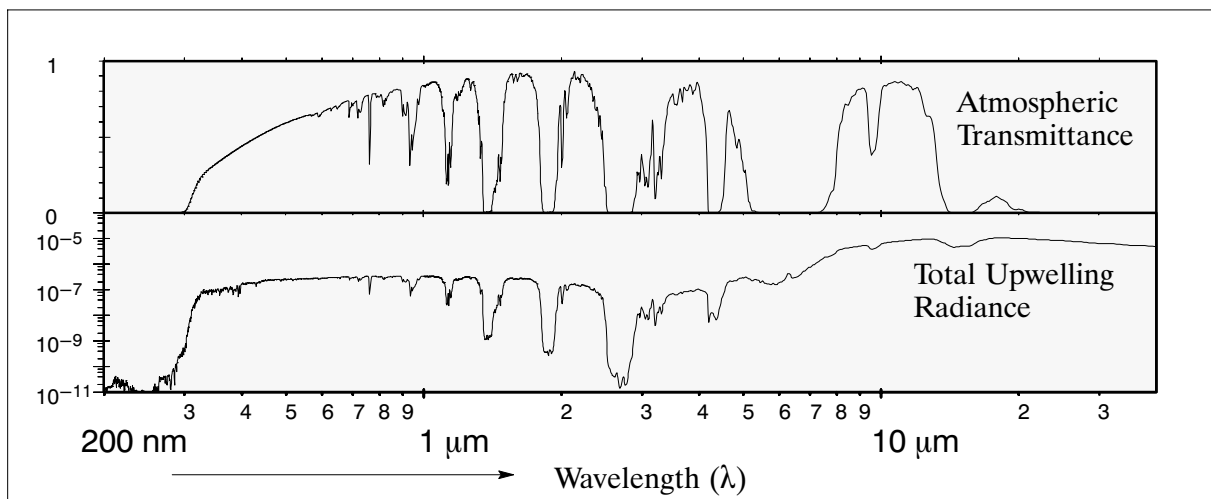


Figure 1570: Atmospheric transmittance and radiance for UV to TIR regions

When electromagnetic radiation from the sun reaches Earth's atmosphere, it may be: (see also **Solar radiation – from Sun to Earth**).

- **Transmitted:** a process by which incident radiation passes through matter with measurable attenuation
- **Reflected:** a process by which incident radiation bounces off the surface of a substance in a predictable or unpredictable direction
- **Scattered:** a process by which incident radiation is dispersed or spread out unpredictably in many directions (see also **Scattering**)

- **Absorbed:** a process by which incident radiation is taken in by the medium. A portion of the radiation is converted into internal heat energy and emitted or reradiated at longer thermal infrared wavelengths.

Atmosphere: The atmosphere is a central component in the Earth system and acts as a natural transport system for energy, water, nutrients and pollutants. It exchanges momentum, heat, water, carbon and all trace gases and aerosols between the oceans and land surfaces. Atmospheric circulation is driven by these interactions, as well as sea–surface temperature, soil moisture and surface albedo. ⁶⁸¹⁴⁾

Since water vapor is the most abundant greenhouse gas, accounting for one to two thirds of the ‘greenhouse effect’, scientists are looking for a better understanding of the coupled processes of clouds, aerosols and atmospheric chemistry, including the global water cycle.

Atmospheric absorption. A process whereby some or all of the energy of electromagnetic radiation is transferred to the constituents of the atmosphere. Absorption by atmospheric gases is dominated by that of water vapor (H₂O), carbon dioxide (CO₂), and ozone (O₃) with smaller contributions from methane (CH₄), carbon monoxide (CO), and other trace gases. Water vapor is rather variable across the Earth’s surface (location) as well as throughout the atmosphere (altitude). CO₂ and CH₄ are essentially uniformly mixed in the atmosphere, hence predictable in their effects (see also **Absorption bands**). ⁶⁸¹⁵⁾ – The sum effect of absorption results in atmospheric opaqueness in many spectral regions as illustrated in Figure 1570. Hence, observational techniques must be tailored to utilize those atmospheric windows through which the surface can be viewed.

Atmospheric attenuation. A process whereby some or all of the energy of electromagnetic radiation is absorbed and/or scattered when passing through the atmosphere. The amount of radiant energy that the atmosphere either removes or adds to that emitted or reflected from the Earth’s surface depends on:

- The constituents of the atmosphere
- The path length of radiation (a function of geometry of the source, surface, and sensor)
- The reflectance of the surface surrounding scene or target area

Atmospheric boundary layer (also referred to as **Planetary boundary layer, PBL**). This boundary layer includes the bottom part of the atmosphere within which the energy exchange processes (between the Earth’s surface and the atmosphere) occur mainly through vertical transport mechanisms of momentum and heat (production of wind shear turbulence plus convective heat turbulence). The whole PBL is heated by convection. Temperature gradients are strongest near the surface, because there convective ‘eddies’ are relatively small and inefficient in carrying heat upward. The thickness of the daytime PBL is typically in the order of a kilometer; however, it may be three times as high with strong heating. The PBL may also be limited by a top inversion. On a clear day the whole PBL is turbulent; it increases rapidly in the morning and only very slowly after the time of maximum heating, until it decreases to a minimum during the night (sensitivity to diurnal cycle).

Atmospheric correction. A problem with spaceborne surface observations is that a large portion of the received signal (about 80%) originates in the atmosphere. Much of this atmospheric signal is due to Rayleigh (or molecular) scattering, primarily from stratospheric ozone. Corrections attributed to Rayleigh scattering are normally estimated taking into account the geometry of a particular scene as well as the extraterrestrial solar radiation, ozone concentration, and atmospheric pressure. Aerosol scattering, primarily encountered in the

6814) Michael Berger, Einar–Arne Herland, Josef Aschbacher, Stephen Briggs, “New Possibilities for Science – ESA’s operational Sentinel missions,” ESA Bulletin, No 140, Nov. 2009, pp. 2–10, URL: <http://esamultimedia.esa.int/multimedia/publications/ESA–Bulletin–140/offline.zip>

6815) A. F. Goetz, J. B. Wellman, W. L. Barnes, “Optical Remote Sensing of the Earth,” Proceedings of the IEEE, Vol. 73, No. 6, June 1985, pp. 950–969

marine boundary layer, represents another variable in the signal estimation. Since it is not possible to make direct measurements of these aerosols and their contribution to atmospheric optical properties, the remote-sensing community has relied on an indirect approach. The ocean is assumed as largely “black” in the VNIR portion of the spectrum; any radiance measured in this spectral region is assumed to originate in the atmosphere. The spectral dependence of aerosol scattering is in this manner propagated into the UV and VIS portion of the spectrum. Atmospheric correction algorithms try to account for all the various signal influences in their processing schemes.

Hyperspectral imaging in the TIR (Thermal Infrared) region at long slant path ranges requires atmospheric correction to enhance the capability of object detection and spectral identification. An algorithm for such a problem is given in the following reference.⁶⁸¹⁶⁾

Atmospheric drag. For LEO spacecraft the atmospheric drag is dependent on the atmospheric density, which may vary significantly along the orbit, because of changes in the satellite’s altitude and geomagnetic influences, but also from day to day, depending mainly on the solar activity. Operational orbit determination must take care of the atmospheric drag effects using atmospheric models (the effective cross-sectional area of a spacecraft may contribute significantly to atmospheric drag depending on orbital altitude and attitude).

Atmospheric layers: Earth’s atmosphere, which is composed of nitrogen, oxygen, water vapor, carbon dioxide and other trace gases, also consists of five layers. These consist of the Troposphere, the Stratosphere, the Mesosphere, the Thermosphere, and the Exosphere. As a rule, air pressure and density decrease the higher one goes into the atmosphere and the farther one is from the surface.

- Troposphere: Closest to the Earth is the Troposphere, which extends from the 0 to between 12 km and 17 km above the surface. This layer contains roughly 80% of the mass of Earth’s atmosphere, and nearly all atmospheric water vapor or moisture is found in here as well. As a result, it is the layer where most of Earth’s weather takes place.
- The Stratosphere extends from the Troposphere to an altitude of ~50 km. This layer extends from the top of the troposphere to the stratopause, which is at an altitude of about 50 to 55 km. This layer of the atmosphere is home to the ozone layer, which is the part of Earth’s atmosphere that contains relatively high concentrations of ozone gas.
- Next is the Mesosphere, which extends from a distance of 50 to 80 km above sea level. It is the coldest place on Earth and has an average temperature of around -85°C (190 K).
- The Thermosphere, the second highest layer of the atmosphere, extends from an altitude of about 80 km up to the thermopause, which is at an altitude of 500–1000 km. The lower part of the thermosphere, from 80 to 550 km, contains the ionosphere – which is so named because it is here in the atmosphere that particles are ionized by solar radiation. This layer is completely cloudless and free of water vapor. It is also at this altitude that the phenomena known as Aurora Borealis and Aurara Australis are known to take place.
- The Exosphere, which is outermost layer of the Earth’s atmosphere, extends from the exobase – located at the top of the thermosphere at an altitude of about 700 km above sea level – to about 10,000 km. The exosphere merges with the emptiness of outer space, and is mainly composed of extremely low densities of hydrogen, helium and several heavier molecules including nitrogen, oxygen and carbon dioxide. The exosphere is located too far above Earth for any meteorological phenomena to be possible. However, the Aurora Borealis and Aurora Australis sometimes occur in the lower part of the exosphere, where they overlap into the thermosphere.

Atmospheric properties (with regard to high-energy radiation). The properties of the Earth’s atmosphere are affected by the sun, but in somewhat different ways at high altitudes

⁶⁸¹⁶⁾ B. A. Gorin, R. C. Blosser, J. Sweet, “New method to optimize atmospheric correction for hyperspectral thermal imaging,” *Optical Engineering*, Vol. 41, No 9, 2002, pp. 2088–2097

than in the lower atmosphere. In the troposphere, the main effect of the sun's radiation is to heat the atmosphere, either directly or indirectly by heating the Earth's surface. At high altitudes (ionospheric region), however, the atmosphere is affected by types of solar radiation (UV, x-ray, gamma-ray) which are being absorbed; these do not penetrate into the lower regions of the atmosphere. [Note: The radio range (microwave region) of the electromagnetic spectrum is limited by the ionosphere at wavelengths greater than a few meters, and by atmospheric absorption at wavelengths shorter than about 2 cm.] – The atmosphere is also affected by energetic charged particles (mainly electrons and protons) which are produced by the sun (directly or indirectly). These radiations not only heat the atmosphere, but may directly affect the chemical composition of the atmosphere (e.g., by dissociating molecules and ionizing atoms and molecules).

Atmospheric refraction. As a signal (electromagnetic radiation) traverses the atmosphere, it experiences propagation delay and bending due to the variable characteristics of the medium through which it is passing. The Earth's ionosphere introduces significant systematic perturbations on all microwave tracking data. At lower frequencies (150 MHz) daytime ionospheric biases can easily reach several kilometers in range, several meters per second in range rate, and up to two or three milliradians in position. Since most of the effects decrease as the inverse square of frequency, modern radiometric systems track at dual and well separated higher frequencies. As a signal traverses the troposphere it experiences a varying refractive index resulting primarily from spatial variations in atmospheric pressure, temperature and humidity. For radiometric technologies, variations in water vapor content is of chief concern. Optical signals have a much weaker dependence on water vapor. The varying refractive index influences the propagating signal in several ways. For optical signals, the most important effect is the varying group velocity where the pulse speeds up as it travels from the ground station to low pressure regions at higher altitudes. This change is a consequence of Snell's law of refraction, which predicts the bending and speed of a light ray as it moves through atmospheric layers with differing refractive indices.⁶⁸¹⁷⁾

Atmospheric sciences. Study of the dynamics and structure of the Earth's atmosphere. There are three main areas:

- **Meteorology.** Primary concern is short-term weather variations in the lower regions of the atmosphere, in particular the troposphere.
- **Climatology.** Primary concern is long-term weather conditions on a global scale.
- **Aeronomy.** Involves research of the atmospheric regions above the lower stratosphere, dealing with such phenomena as ionospheric physics, photochemical processes of the upper atmosphere, aurorae, magnetospheric storms, etc. In general, aeronomy is the science that studies all planetary atmospheres in which physical and chemical processes, resulting from the dissociation and ionization phenomena under the influence of the solar radiation, occur.

Atmospheric window. Spectral bands for which atmospheric attenuation is relatively low (i.e., the bands for which the atmosphere presents minimal interference).

Atomic clocks: An atomic clock is a type of clock that uses an atomic resonance frequency standard as its timekeeping element. They are the most accurate time and frequency standards known, and are used as primary standards for international time distribution services, to control the frequency of television broadcasts, and in global navigation satellite systems such as GPS, GLONASS, or Galileo.⁶⁸¹⁸⁾

In 1967, the cesium atom's natural frequency was formally recognized as the new SI (International System of Units) time standard. SI has defined the second as the duration of

6817) Ivan I. Mueller, S. Zerbini, "The Interdisciplinary Role of Space Geodesy," Lecture Notes in Earth Sciences, Springer Verlag, 1989, p. 187

6818) http://en.wikipedia.org/wiki/Atomic_clock

9,192,631,770 cycles (Hz) of radiation corresponding to the transition between two energy levels of the caesium-133 atom. This definition makes the caesium oscillator (often called an atomic clock) the primary standard for time and frequency measurements.

Atomic clocks use the precise **microwave signal** that electrons in atoms emit when they change energy levels.

- Early atomic clocks were based on masers
- In the first decade of the 21st century, the most accurate atomic clocks are based on absorption spectroscopy of cold atoms in atomic fountains. – Example: NIST-F1 (National Institute of Standards and Technology) is a caesium fountain atomic clock that serves as the United States' primary time and frequency standard (since 2005).
- In March 2008, physicists at NIST demonstrated **optical atomic clocks** based on individual mercury and aluminum ions – referred to as “quantum logic clock.” (so called because it borrows the logical processing used for atoms storing data in experimental quantum computing).⁶⁸¹⁹⁾

Atomic oxygen. Neutral atomic oxygen is the dominant atmospheric species at typical LEO altitudes of satellites. Its altitude range includes the mesosphere (50–100 km), the thermosphere (100–400 km), and the lower part of the exosphere (>400 km). Atomic oxygen, the most abundant atmospheric species over most of this altitude range, can affect a spacecraft's operational capability. Adverse influences include material degradation. Of particular concern are the following effects: impact of particulate matter (debris), of high-energy UV radiation and of x-ray radiation, both of which are predominantly of solar origin. Degradation due to these phenomena is often synergistic and must be taken into account in the S/C design process, particularly for long-term LEO missions. – Atomic oxygen is formed in the lower thermosphere by photodissociation of molecular oxygen induced by solar UV radiation ($\lambda < 243$ nm). Atomic oxygen is a highly reactive species. Spaceborne instruments for the measurement of atomic oxygen include non-optical devices to derive flux and/or density, and those using optical measurements. The latter involves the measurement of the emission, scattering, or absorption of radiation (in the VIS, IR or UV ranges) caused by atomic oxygen. Typical non-optical devices are: a) mass spectrometers, b) actinometers, and c) catalytic probes.⁶⁸²⁰⁾

Aurora. Light radiated by ions in the Earth's upper atmosphere, mainly near the geomagnetic poles, stimulated by bombardment of energetically charged particles of the solar wind. Aurorae appear about two days after a solar flare and reach their peak about two years after a sunspot maximum. The northern aurora is also referred to as the ‘aurora borealis’ while the southern aurora is also called ‘aurora australis.’⁶⁸²¹⁾

For many centuries the aurora was referred to as the “northern lights” because it is a polar phenomenon and lies to the north when viewed from Europe. An aurora is a visible manifestation of “space weather” – the highly variable interaction between the sun and the Earth's magnetosphere, upper atmosphere, and ionosphere. The aurora is visible because of interaction of electrons and protons that are accelerated along the Earth's magnetic field lines from the magnetosphere (the cavity in the solar wind created by the Earth's magnetic field) into the Earth's atmosphere, where they undergo collisions with the background gas.

In 2006, new results by the Cluster mission of ESA clearly show that multi-point observations are the key to understanding the magnetic substorm phenomenon. The Cluster mission has established that high-speed flows of electrified gas, known as BBFs (Bursty Bulk

6819) “Aluminum Ion Drives Most Precise Quantum Logic Clock Ever,” Space Daily, Feb. 5, 2010, URL: http://www.spacedaily.com/reports/Aluminum_Ion_Drives_Most_Precise_Quantum_Logic_Clock_Ever_999.html

6820) J. J. Osborne, I. L. Harris, G. T. Roberts, A. R. Chambers, “Satellite and rocket-borne atomic oxygen sensor techniques,” Review of Scientific Instruments, Vol. 72, No 11, Nov. 2001, pp. 4025–4041

6821) L. J. Paxton, C.–I. Meng, “Auroral Imaging and Space-Based Optical Remote Sensing,” Johns Hopkins APL Technical Digest, Vol. 20, No 4, 1999, pp. 556–569

Flows), in the Earth's magnetic field are the carriers of decisive amounts of mass, energy and magnetic perturbation towards the Earth during magnetic substorms. When substorms occur, energetic particles strike our atmosphere, causing aurorae to shine. The analysis from combined observations from three out of the four Cluster spacecraft revealed that 95.5% of the substorms are accompanied by BBFs (it seems possible that all substorms are accompanied by BBFs).^{6822) 6823)}

Another key result of the analysis is that the average BBF duration is longer than previously estimated. Single satellite observations confirmed past results that the BBF duration was around 10 minutes. However, by combining the data from three of the Cluster spacecraft, the observations reveal an average duration almost twice as long: 18 minutes and 25 seconds. So again, the multiple spacecraft data offered by Cluster was found to reveal more about the Earth's magnetic environment than data collected by single spacecraft.

In a new study, Cluster has investigated violent magnetic events called substorms, which result from variations in the stream of charged particles emitted in the solar wind colliding with Earth's magnetic shield – the magnetosphere.⁶⁸²⁴⁾

During a substorm, the tail of Earth's magnetosphere is compressed and blows powerful streams of high-energy plasma towards the planet at speeds that may reach a few thousand kilometers per second. This allows plasma particles to infiltrate the upper layer of Earth's atmosphere to produce auroras.

Known as 'bursty bulk flows', they are short-lived, lasting typically only 10–20 minutes. The new study finds that, despite their brevity, these flows can carry a much more significant amount of energy than previously thought – around a third of the total energy that eventually reaches Earth during an auroral display.

Auroral oval. Refers to the approximately circular band in the northern or southern hemisphere where aurora are most intense. The near-midnight portion of the oval, where some of the brightest emissions occur, is located about $\pm 65^\circ$ latitude. The mean diameter of the oval is about 4000 km.

Avionics. The term is derived from the expression "aviation electronics" (a contraction of both terms) and refers to all types of instruments for use in the navigation function (sensing, control, and performance) of aircraft or spacecraft.

An avionics system of a spacecraft may include some of the following elements: 1) a data bus (like MIL-STD-1553B or SpaceWire) which interfaces with all devices; 2) typical sensing devices make up the AOCS (Attitude and Orbit Control System) like: gyro, Earth horizon sensor, IMU (Inertial Measurement Unit), GPS receiver, magnetometer, and star sensor; 3) typical control devices (actuators) are: torque rods, reaction wheels, etc. for attitude control, and a thruster system for orbit or attitude changes.

For an aircraft the avionics system includes the attitude gyro and any number of instruments that indicate power, torque meter (in turboprops), and exhaust pressure ratio indicator (in turbojets). Performance instruments include the altimeter, Machmeter, turn and slip indicator, and varied devices that show airspeed, vertical velocity, and angle of attack. Electronic radio navigation equipment ranges from radar to instrument landing systems.

Avionics engineering is the art of electronically integrating everything on the spacecraft into a smoothly operating unit. At the start of the 21 century, spacecraft avionics has advanced beyond merely wiring together all the separate boxes of functioning subsystems. Now space-

6822) J. B. Cao, Y. D. Ma, G. Parks, H. Rème, I. Dandouras, R. Nakamura, T. L. Zhang, Q. Zong, E. Lucek, C. M. Carr, Z. X. Liu, G. C. Zhou, "Joint observations by Cluster satellites of bursty bulk flows in the magnetotail" *Journal of Geophysical Research*, Vol. 111, 2006, A04206, doi:10.1029/2005JA011322

6823) "ESA's Cluster mission establishes why Earth's aurorae shine," http://www.esa.int/esaCP/SEM RKHZ7OOE_index_0.html

6824) "From Solar Activity to Stunning Aurora," ESA, April 15, 2013, URL: http://www.esa.int/Our_Activities/Space_Science/From_solar_activity_to_stunning_aurora

craft engineers are working to put all the interfaces and electronics together on a single microchip along with software. This engineering advance has required a leap in thinking about how systems work together.

Azimuth plane (direction). Observation by an instrument in the along-track direction, i. e. in the direction of the subsatellite track. In general the azimuth is the angle of horizontal deviation, measured clockwise, of a bearing from a standard direction.

Background noise. Refers to the noise present in a sensor (detector) independent of the signal strength or ambient temperature. Normally caused by thermal, generation–recombination characteristics or $1/f$ effects.

Backscatter. Scattering of radiation (or particles) through angles greater than 90° with respect to the original direction of motion.

Band. A specification of a spectral range (say, from $0.4 - 0.5 \mu\text{m}$) that is used for radiative measurements. The term ‘channel’ is also in common use with the same meaning as ‘band’. In the ITU convention (see Table 966) for the electromagnetic spectrum, the term ‘band’ refers to a specific frequency range, designated as L–band, S–band, X–band, etc.

Band–to–band registration (also referred to as co–registration). Refers to multispectral image resolution, i.e. how well the same scene is recorded in different spectral bands. Co–registration of spectral bands is measured by the displacement of corresponding pixels in two different bands from their ideal relative location. Two pixels are “corresponding” if their footprints should ideally coincide or if the footprint of one should ideally lie within a specific region of the footprint of the other.

Bandpass. Defined as the frequency band(s) over which a microwave radiometer detects radiation. The equivalent for IR radiometers is the filter response.

Bandpass filter. A filtering device that allows transmission of only a narrow band of frequencies (the other frequencies are blocked out). The spectral width of this filter is characterized by its bandwidth.

Bandwidth. Range of frequencies over which an instrument (or communication link) can be used. It is usually specified in terms of 3 dB points that is, frequencies at which the response has fallen by 3 dB or 30% from the mid–frequency response. Bandwidth may also refer to the width of a spectral feature as measured by a spectroscopic instrument.

Baroclinic waves (disturbances). Any migratory cyclone more or less associated with strong baroclinity of the atmosphere, as evidenced on synoptic charts by temperature gradients in the constant–pressure surfaces, vertical wind shear, and concentration of solenoids in the frontal surface near the ground.

Baseband. Band of frequencies, usually the lowest frequencies in a microwave communications system, where basic information is assembled. This spectrum is generally that provided to the microwave system to be delivered to a distant point in the same format and information content.

Bathymetry. Refers to the measurement of water body depths, in particular ocean floor surveys. Generally, bathymetry surveys cannot be directly performed from a satellite. However, there are some areas of satellite applications: – bathymetry surveys in coastal regions (with a SAR instrument) or of shallow bodies of water; the other method is the interpretation and correlation of radar altimeter data (the technique relies on the assumption that the relationship between the gravity field and bathymetry is uniform over relatively small areas ($\approx 200 \times 200 \text{ km}$). Bathymetry is a necessary prerequisite in the study of the ocean’s role in, and response to, climate and climate change. Bathymetry represents a control on both, ocean currents and mixing [ocean currents move a vast volume heat and mass (energy storage) over great distances, affecting the climate of large regions].

Beamsplitter (also referred to as beam combiner). A mirror, sometimes built into a prism, with the ability of reflecting part of a beam of radiation and transmitting the other part. The ‘splitting’ or diverting is performed on the energy level (frequency–selective surfaces), not on the spectral level (no spectral separation by dispersion). Such a partially diverted beam may be used in color separation cameras, or for the superposition of images in special cameras or in Fourier Transform Spectrometers (FTS), generating an interferogram in combination with an interferometer.

Spectral beam combining inevitably generates output beams with several (or many) spectral components, thus spanning a significant optical bandwidth. This means that the spectral brightness is even reduced compared with that of the single emitters. This does not matter for some applications while excluding others, where a narrow–bandwidth output is required.

Bias. In electronics the term refers to the application of a voltage between two terminals (electrodes) resulting in current flow (also referred to as ‘forward bias’). The term ‘reverse bias’ refers to the application of a voltage in such a way that no current can flow. The term ‘unbiased’ designates that no voltage is applied.

Beat wave. A composite wave formed by the superposition of two waves having different frequencies (f_1, f_2) and wavenumbers (k_1, k_2). Beat waves form at the sum and difference frequencies ($f_1 \pm f_2$) and wavenumbers ($k_1 \pm k_2$). See also **heterodyne detection**.

Biological productivity. The amount of organic matter, carbon, or energy that is accumulated during a given time period.

Bioluminescence. Refers to the production of light from chemiluminescent reaction in living organisms. Although bioluminescence is very dim, it features prominently in the ecology of the seas, occurring in all oceans; it is produced by a wide variety of marine plankton and nekton.

Biomass. The total dry organic matter or stored energy content of living organisms that is present at a specific time in a defined unit (community, ecosystem, crop, etc.) of the Earth’s surface.

Biomass burning. A recognized major source of trace gases, including CO_2 , NO_2 , CO , CH_4 , and of aerosol particles. It takes on many forms: burning of forested areas for land clearing, extensive burning of grasslands and savannas to sustain grazing lands, burning of harvest debris, use of biomass fuel for heating, forest fires induced by lightning or other hazards. The emissions of biomass burning represent a large perturbation to global atmospheric chemistry, especially in the tropics.

Biosphere. The portion of the Earth and its atmosphere that can support life. The part (reservoir) of the global carbon cycle that includes living organisms (plants, animals,) and life–derived organic matter (litter, detritus). The terrestrial biosphere includes the living biota (plants and animals), litter and soil organic matter on land; the marine biosphere includes the biota and detritus in the oceans.

Bistatic system. The bistatic remote–sensing concept refers to a measurement arrangement in which the transmitter and receiver locations are separated by a distance comparable to that of the target distance. – In contrast, **monostatic radars** employ a transmitter and receiver (Tx/Rx) at the same location (often using the same antenna) and measure the back-scattered radiation. The great majority of all radars (SAR instruments, Doppler radars, etc.) in use today are monostatic.

Blackbody (BB). An idealized body that absorbs all the radiation incident upon it and re-radiates it according the Planck’s law.

Black holes: A black hole is a region of space from which nothing, not even light, can escape. The theory of general relativity predicts that a sufficiently compact mass will deform space-

time to form a black hole. Around a black hole there is an undetectable surface called an **event horizon** that marks the point of no return. It is called "black" because it absorbs all the light that hits the horizon, reflecting nothing, just like a perfect black body in thermodynamics. Quantum mechanics predicts that black holes emit radiation like a black body with a finite temperature. This temperature is inversely proportional to the mass of the black hole, making it difficult to observe this radiation for black holes of stellar mass or greater. ⁶⁸²⁵⁾

Black holes that originate from the collapse of massive stars are very compact objects, enclosing up to a few tens of solar masses within a radius of only a few kilometers. Black holes are so dense that nothing, not even light, can escape their gravity. In theory, these black holes should therefore be impossible to observe; however, when a black hole is part of a binary stellar system, interesting effects arise that can uncover the surroundings of these otherwise 'invisible' objects. It is this phenomenon that enables astronomers to probe the environment of the black hole.

In a binary system, a black hole and a normal star are gravitationally bound and orbit each other around their common centre of mass. With its intense gravitational field, the black hole draws matter from its companion, and the stripped material spirals around the black hole, forming an accretion disc. As friction in the disc heats the material up to millions of degrees, making it shine in X-rays, these objects are known as XRBs (X-Ray Binaries). First observed in the 1960s, soon after observations at these wavelengths became possible, these objects raised immediate interest as black hole candidates; furthermore, in the following decades, data gathered in the radio band revealed jets of relativistic particles emanating from several XRBs, suggesting that a link exists between accretion and ejection of matter in the proximity of such stellar black holes.

Astronomers call these objects 'microquasars' because they appear as miniature versions of quasars — the nuclei of active galaxies that harbor, in their cores, supermassive black holes that are millions of times more massive than their stellar counterparts. In spite of their very different sizes, black holes in both types of systems exhibit very similar dynamics, vigorously accreting matter from their surroundings via a disc and funnelling part of it, by means of the disc rotation, into highly collimated, bipolar jets of particles that are released at relativistic speeds.

There is evidence of a black hole environment in the Cygnus–1 binary system. Cygnus–1 is one of the brightest galactic sources in the high–energy sky and one of the first X–ray binaries that was discovered (soon after the advent of X–ray astronomy in the 1960s) in the Milky Way. Cygnus X–1 is also the first galactic source for which optical measurements, in the early 1970s, suggested the presence of a black hole, as both the optical and X–ray emission exhibit variability on very short time scales. ⁶⁸²⁶⁾

Two main classes of black holes have been extensively observed. Stellar–mass black holes with three to dozens of times the Sun's mass are spread throughout our Milky Way galaxy, while supermassive monsters weighing 100,000 to billions of solar masses are found in the centers of most big galaxies, ours included. Astronomers suspect there's an in–between class called intermediate–mass black holes, weighing 100 to more than 10,000 solar masses, but they have not been conclusively observed to date. ⁶⁸²⁷⁾

A stellar–mass black hole forms when a star with more than 20 solar masses exhausts the nuclear fuel in its core and collapses under its own weight. The collapse triggers a supernova explosion that blows off the star's outer layers. But if the crushed core contains more than about three times the Sun's mass, no known force can stop its collapse to a black hole. The

6825) http://en.wikipedia.org/wiki/Black_hole

6826) "INTEGRAL discovers gamma rays originating from black hole jets," ESA, March 24, 2011, URL: <http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=48587>

6827) "What Are Black Holes?," NASA, 22 May 2019, URL: https://www.nasa.gov/vision/universe/starsgalaxies/black_hole_description.html

origin of supermassive black holes is poorly understood, but we know they exist from the very earliest days of a galaxy's lifetime.

Once born, black holes can grow by accreting matter that falls into them, including gas stripped from neighboring stars and even other black holes.

In 2019, astronomers using the [Event Horizon Telescope \(EHT\)](#) — an international collaboration that networked eight ground-based radio telescopes into a single Earth-size dish — captured an image of a black hole for the first time. It appears as a dark circle silhouetted by an orbiting disk of hot, glowing matter. The supermassive black hole is located at the heart of a galaxy called M87, located about 55 million light-years away, and weighs more than 6 billion solar masses. Its event horizon extends so far it could encompass much of our solar system out to well beyond the planets.



Figure 1571: The first picture of a black hole was made using observations of the center of galaxy M87 taken by the Event Horizon Telescope. The image shows a bright ring formed as light bends in the intense gravity around a black hole 6.5 billion times the Sun's mass. (image credit: Event Horizon Telescope Collaboration)

Another first related to black holes came in 2015 when [scientists first detected gravitational waves](#), ripples in the fabric of space as predicted a century earlier by Albert Einstein's general theory of relativity. The waves were observed at the [National Science Foundation's Laser Interferometer Gravitational-wave Observatory \(LIGO\)](#) detectors, located in Livingston, Louisiana, and Hanford, Washington. Their source was the merger of two orbiting black holes that spiraled into each other 1.3 billion years ago. Since then, LIGO and other facilities have observed numerous black hole mergers via the gravitational waves they produce.

A black hole is conventionally thought of as an astronomical object that irrevocably consumes all matter and radiation which comes within its sphere of influence. Physically, a black hole is defined by the presence of a singularity, i.e., a region of space, bounded by an 'event horizon', within which the mass/energy density becomes infinite, and the normally well-behaved laws of physics no longer apply.

However, as an article in the January issue of the journal *Nature Astronomy* demonstrates, a precise and agreed definition of this 'singular' state proves to be frustratingly elusive.

Its author, Dr. Erik Curiel of the Munich Center for Mathematical Philosophy at Ludwig–Maximilians–Universitaet, summarizes the problem as follows: "The properties of black holes are the subject of investigations in a range of subdisciplines of physics – in optical physics, in quantum physics and of course in astrophysics. But each of these specialties approaches the problem with its own specific set of theoretical concepts."

Erik Curiel studied Philosophy as well as Theoretical Physics at Harvard University and the University of Chicago, and the primary aim of his current DFG (Deutsche Forschungsgemeinschaft) – funded research project is to develop a precise philosophical description of certain puzzling aspects of modern physics.

"Phenomena such as black holes belong to a realm that is inaccessible to observation and experiment. Work based on the assumption that black holes exist therefore involves a level of speculation that is unusual even for the field of theoretical physics."

However, this difficulty is what makes the physical approach to the nature of black holes so interesting from the philosophical point of view. "The physical perspective on black holes is itself inextricably bound up with philosophical issues relating to ontological, metaphysical and methodological considerations," says Curiel.

"Surprising" and "eye-opening" insights: During the preparation of his philosophical analysis of the concept of black holes for *Nature Astronomy*, the author spoke to physicists involved in a wide range of research fields. In the course of these conversations, he was given quite different definitions of a black hole.

Importantly, however, each was used in a self-consistent way within the bounds of the specialist discipline concerned. Curiel himself describes these discussions as "surprising" and "eye-opening".

For astrophysicist Avi Loeb, "a black hole is the ultimate prison: once you check in, you can never get out." On the other hand, theoretical physicist Domenico Giulini regards it as "conceptually problematical to think of black holes as objects in space, things that can move and be pushed around."

Curiel's own take-home-message is that the very diversity of definitions of black holes is a positive sign, as it enables physicists to approach the phenomenon from a variety of physical perspectives. However, in order to make productive use of this diversity of viewpoints, it will be important to cultivate a greater awareness of the differences in emphasis between them.

Table 968: Philosophy: What exactly is a black hole? 6828) 6829)

Blaze wavelength. The wavelength of the highest efficiency for a ruled diffraction grating, the "blaze" being the controlled shape of the rulings on the grating.

6828) "Philosophy: What exactly is a black hole?," *Space Daily*, 15 February, 2019, URL: http://www.spacedaily.com/reports/Philosophy_What_exactly_is_a_black_hole_999.html

6829) Erik Curiel, "The many definitions of a black hole," *Nature Astronomy*, Vol. 3, January 2019, pp: 27–34, <https://doi.org/10.1038/s41550-018-0602-1>, URL: <https://tinyurl.com/y6fyb9cb>

Blooming. Refers to the saturation effect in image detection devices, like CCDs.

Body–pointing. Refers to the pointing technique of an instrument within the field of regard. The instrument is pointed along with its platform (satellite) into the desired direction.

Bolometer. A detector type making use of the change in electrical resistance of certain materials (with small thermal capacity) when their temperature is changed. The resistance of most conductors varies with temperature, this change in resistance is measured by the bolometer. Bolometers are suitable detectors for observations the infrared and microwave regions.

Boresight. A technique for aligning sensors or detectors on a target in parallel.

Bragg scattering theory. According to this theory the normalized radar cross–section (NRCS) is proportional to the spectral energy density of the Bragg waves, i.e. of those surface waves with wave numbers k_B that satisfy the Bragg resonance condition:

$$k_B = \frac{4\pi \sin \theta}{\lambda_o} \quad \text{where } \lambda_o \text{ denotes the radar wavelength and } \theta \text{ the incidence angle.}$$

BRDF (Bidirectional Reflectance Distribution Function). Specifies the behavior of surface scattering as a function of illumination and view angles at a particular wavelength. BRDF is defined as being the ratio of the reflected radiance to the incident flux per unit area.⁶⁸³⁰

All remote sensing of Earth’s surface in the solar wavelengths is impacted by the BRDF, all Earth surfaces scatter light anisotropically. The BRDF describes the angular distribution of scattered light and is thus what most remote sensing instruments sample. The BRDF is dependent on the structural as well as the optical characteristics of surfaces and multiple samples of the BRDF may be exploited to retrieve structural parameters.

Generally, multi–angle and multispectral remote sensing furnishes measurements of BRDF. The BRDF is a property of the surface material and its roughness, and depends on 3D geometry of incident and reflected elementary radiation. It is used in many Earth science remote sensing applications, e.g. derivation of surface albedo, calculation of radiative forcing, land cover classification, cloud detection, atmospheric corrections, aerosol optical properties.

Brightness temperature. A concept referring to the equivalent blackbody temperature for a given frequency (range) according to Planck’s law. The term brightness temperature is often employed for data of radio/microwave observations where the radiation is in the Rayleigh–Jeans tail of the thermal distribution. It means that the source emits (at the frequency of interest) the same amount of radiation as a blackbody at the brightness temperature. Intensities are measured in terms of brightness temperature (that is, the temperature a blackbody would have if it emitted an equal intensity of radiation at the same frequency). Examples of brightness temperature applications:

- Measurement and/or computation of the ‘top of the atmosphere brightness temperature’ or ‘troposphere moisture content’ from data of particular channels of such sensors as: AVHRR, TOVS, etc.
- The measurement of ocean surface roughness at microwave frequencies (with a radiometer) permits estimates of ocean–surface wind speeds. The method employs the concept of brightness temperature anisotropy which increases with ocean–surface roughness. The SSM/I sensor of the DMSP series uses this principle to map ocean surface wind speeds.
- The Earth’s surface brightness temperature can be measured by channel 6 (TIR) of the Landsat TM sensor, or by the MWR instrument of ERS missions.

⁶⁸³⁰ F. E. Nicodemus, J. C. Richmond, J. J. Hsia, I. W. Ginsberg, T. Limperis, “Geometrical Considerations and Nomenclature for Reflectance,” National Bureau of Standards, US Department of Commerce, Washington, D.C. 1977

Cadastre. An official (governmental) land registry defining the ownership of a parcel along with ancillary information (description of parcel location, boundaries, shape and size, inventory of actual features and structures, value for taxation, etc.). Positional accuracies are an important issue of such registries. – Cadastral mapping takes many forms around the world, based on current and historic land registry, land reform policies, and available funding levels. In Europe the cadastre is linked to the legal land registration system within the context of a national geodetic reference system. In the US and Canada there is no central land registry (land registry information is maintained at multiple levels). In all parts of the world, however, land ownership information plays a key role in defining local and national economies and in managing natural resources and handling environmental issues.

Calibration. Characterization of a sensor (radiometer, spectrometer, etc., see also chapter Q.2) in the spatial, spectral, temporal and polarization responsive domains. The term ‘calibration’ is being used so often by different people that it has several additional meanings, such as:

1. The activities involved in adjusting an instrument to be intrinsically accurate, either before or after launch (i.e. ‘instrument calibration’).
2. The process of collecting instrument characterization information (scale, offset, nonlinearity, operational and environmental effects), using either laboratory standards, field standards, or modeling, which is used to interpret instrument measurements (i.e. ‘data calibration’).

Candela (cd). A unit of luminous intensity equal to one sixtieth of the luminous intensity of one square centimeter (1 cm^2) of a blackbody surface at the solidification point of platinum.

Carbon cycle. A sequence of conversion processes from matter into energy. All reservoirs and fluxes of carbon; usually thought of as a series of the four main reservoirs of carbon interconnected by pathways of exchange. The four reservoirs – regions of the Earth in which carbon behaves in a systematic manner – are the atmosphere, terrestrial biosphere (usually includes freshwater systems), oceans, and sediments (includes fossil fuels). Each of these global reservoirs may be subdivided into smaller pools ranging in size from individual communities or ecosystems to the total of all living organisms (biota). Carbon is exchanged from reservoir to reservoir by various chemical, physical, geological, and biological processes.

Carbon Nanotubes (CNTs): CNTs are allotropes of carbon with a cylindrical nanostructure. Nanotubes have been constructed with a length–to–diameter ratio of up to 132,000,000:1, significantly larger than for any other material. These cylindrical carbon molecules have unusual properties, which are valuable for nanotechnology, electronics, optics and other fields of materials science and technology. In particular, owing to their extraordinary thermal conductivity and mechanical and electrical properties, carbon nanotubes find applications as additives to various structural materials.⁶⁸³¹⁾

Nanotubes are members of the fullerene structural family. Their name is derived from their long, hollow structure with the walls formed by one–atom–thick sheets of carbon, called graphene. These sheets are rolled at specific and discrete (“chiral”) angles, and the combination of the rolling angle and radius decides the nanotube properties; for example, whether the individual nanotube shell is a metal or semiconductor. Nanotubes are categorized as single–walled nanotubes (SW–CNTs) and multi–walled nanotubes (MW–CNTs). Individual nanotubes naturally align themselves into “ropes” held together by van der Waals forces, more specifically, π –stacking. The fundamental building block of CNTs is the very long, all–carbon cylindrical single–wall CNT (SW–CNT), one atom in wall thickness and tens of atoms around the circumference (typical diameter $\sim 1\text{--}2 \text{ nm}$).⁶⁸³²⁾

Applied quantum chemistry, specifically, orbital hybridization best describes chemical bonding in nanotubes. The chemical bonding of nanotubes is composed entirely of sp^2

6831) “Carbon nanotube,” URL: http://en.wikipedia.org/wiki/Carbon_nanotube

6832) Mahdi Pourfath, “Numerical Study of Quantum Transport in Carbon Nanotube Based Transistors,” Dissertation, Technical University of Vienna, Austria, Juli 2007, URL: <http://www.iue.tuwien.ac.at/phd/pourfath/diss.html>

bonds, similar to those of graphite. These bonds, which are stronger than the sp^3 bonds found in alkanes and diamond, provide nanotubes with their unique strength.

- **Strength:** Carbon nanotubes are the strongest and stiffest materials yet discovered in terms of tensile strength and elastic modulus respectively. This strength results from the covalent sp^2 bonds formed between the individual carbon atoms. Since carbon nanotubes have a low density for a solid of $1.3\text{--}1.4\text{ g/cm}^3$, its specific strength of up to $48,000\text{ kNm/kg}$ is the best of known materials, compared to high-carbon steel's 154 kNm/kg .
- **Hardness:** Standard single-walled carbon nanotubes can withstand a pressure up to 24 GPa without deformation.
- **Kinetic properties:** Multi-walled nanotubes are multiple concentric nanotubes precisely nested within one another. These exhibit a striking telescoping property whereby an inner nanotube core may slide, almost without friction, within its outer nanotube shell, thus creating an atomically perfect linear or rotational bearing. This is one of the first true examples of molecular nanotechnology, the precise positioning of atoms to create useful machines.
- **Electrical properties:** Because of the symmetry and unique electronic structure of graphene, the structure of a nanotube strongly affects its electrical properties. For a given (n,m) nanotube, if $n = m$, the nanotube is metallic; if $n - m$ is a multiple of 3, then the nanotube is semiconducting with a very small band gap, otherwise the nanotube is a moderate semiconductor. Thus all armchair $(n = m)$ nanotubes are metallic, and nanotubes $(6,4)$, $(9,1)$, etc. are semiconducting.
- **Optical properties:** In general, the optical properties of carbon nanotubes refer specifically to absorption, photoluminescence, and Raman scattering.
- **CNTs (Carbon Nanotube)** are nanostructures with extraordinary field emission properties like high current density, low driving voltage and long time stability, because of their high electrical conductivity, high aspect ratio for geometrical field enhancement and superior thermal stability.

Table 969: Some properties of graphene carbon nanotubes

Carrier. An electromagnetic continuous wave (CW) in a communication path (basic center frequency of a signal) which does not carry information but is generally modulated by another wave (subcarrier) which contains the information.

Carrier-phase. Refers to the fraction of a cycle, often expressed in degrees (360° to a cycle). Carrier-phase can also mean 'the number of complete cycles plus a fractional cycle.' In GPS terminology, carrier-phase refers to a receiver capable of locking onto a GPS signal and keeping track of the whole number of cycles of the carrier; this method creates a cumulative phase of the signal which is also known as 'integrated Doppler.' Much higher ranging accuracies can be obtained with carrier-phase than without carrier-phase tracking.

A GPS receiver determines the biased distance between the electrical phase center of its antenna and the phase center of a GPS satellite's transmitting antenna as a pseudorange or carrier-phase measurement. This distance measure is biased due to the lack of synchronization between the satellite and the receiver clocks, atmospheric propagation delays ambiguities, and other factors. To determine the position of the receiving antenna, the receiver's operating software combines a number of simultaneous measurements on different GPS satellites with information on the position of the satellites, the offsets of the satellite clocks, and other parameter values in an accurate theoretical model of the measurements. The precise GPS ephemeris produced by the IGS (International GPS Service) and others

refer to the satellite center of mass (the offset between the center of mass and the satellite's antenna must be accurately known).

Catadioptric telescope (see also Schmidt telescope under Telescopes). Refers to a telescope design with a large FOV to eliminate image distortions (a catadioptric telescope design incorporates the best features of both, the refractor and reflector, i.e., it has both reflective and refractive optics. The Schmidt telescope has a spherically shaped primary mirror. Since parallel light rays, that are reflected by the center of a spherical mirror, are focused farther away than those reflected from the outer regions, Schmidt introduced a thin lens (called the correcting plate) at the radius of curvature of the primary mirror. Since this correcting plate is very thin, it introduces little chromatic aberration. The resulting focal plane has a field of view several degrees in diameter.

Charge–Coupled Device (CCD). A CCD is a photosensitive solid–state imaging sensor (detector) implemented with large–scale integration technology (normally based on MOS technology). A MOS capacitor is a three–layer sandwich formed by positioning a metal electrode, insulated by a layer of silicon dioxide, onto a silicon substrate. Incident radiation into the system is sampled by photodetectors, converted into an electronic charge and trapped in the depletion region of the substrate. The isolated charge packets are transported by manipulating potential wells (place of minimum potential) within the substrate. The ability to store a charge is fundamental to the operation of CCDs. It corresponds to a memory device storing analog quantities. – CCD readout techniques employ clock–controlled circuits which transfer these charges to a matching grid of elements and shift all charges by one row at a time. – The CCD technology was first demonstrated in 1969 at the Bell Laboratories. See also chapter Q.4.2.1.

Charge Injection Device (CID). A photo–sensitive image sensor (detector) implemented in large–scale integration technology. Charge packets are typically measured by injecting them into a substrate or by shifting charge packets under an electrode to induce a voltage on the capacitance formed by the electrode and the substrate. A CID can be randomly addressed. The pixel structure is contiguous with maximum surface to capture incident light which is useful for sub–pixel measurement (Q.4.2.2).

Chemiluminescence. Emission of light as a consequence of a chemical reaction, the result of thermal generation of electronic excited states. Chemiluminescence can be seen when occurring in the dark. – A number of chemical reactions generate products not in their lowest energy states, but rather in upper levels. That is, some of the exothermicity of the reaction is channeled internally into electronic, vibrational, or rotational energy of one or more of the products, rather than being released as heat. The excited product molecules may emit this energy as light, known as chemiluminescence because of the chemical source of energy. – The term of **surface chemiluminescence** belongs also into this context. In this scheme air is passed over a chemiluminescent plate causing the gas (eg., ozone) molecules to diffuse into the coating of the plate and in turn generating a chemiluminescent reaction. The reaction sequence causes the emittance of light (radiation) whose intensity is proportional to the ozone concentration.

Chirp principle. A microwave modulation technique in which the frequency of the transmitted microwave pulse is not constant but linearly changed in a positive sense (up–chirp) or in a negative sense (down–chirp). A frequency–modulated chirp is a signal with a (linear) increase in frequency or pitch.

Chlorofluorocarbons (CFCs). A family of inert, nontoxic, and easily liquefied chemicals used in refrigeration, air conditioning, packaging, and insulation, or as solvents or aerosol propellants. Because they are not destroyed in the lower atmosphere, they drift into the upper atmosphere, where – given suitable conditions – their chlorine components destroy ozone.

Chlorophyll. A green pigment essential for photosynthesis found in plants. It usually occurs in discrete bodies (chloroplasts) in plant cells, and is what makes green plants green. In re-

mote sensing of aquatic ecosystems, the reflected radiance is related to the concentration of chlorophyll and other associated pigments. Since chlorophyll is green, the color of reflected light changes from blue to green as the concentration of chlorophyll increases. The concentration of chlorophyll is used to estimate the abundance of phytoplankton in ocean waters, and hence the abundance of ocean biota.⁶⁸³³⁾

Climate. The statistical collection and representation of the weather conditions for a specified area during a specified time interval, usually on a decade–scale, together with a description of the state of the external system or boundary conditions. The properties that characterize the climate are thermal (temperatures of the surface air, water, land, and ice), kinetic (wind and ocean currents, together with associated vertical motions and the motions of air masses, humidity, cloudiness and cloud water content, groundwater, lake winds, and water content of snow on land and sea ice), and static (pressure and density of the atmosphere and ocean, composition of the dry air, salinity of the oceans, and the geometric boundaries and physical constants of the system). These properties are interconnected by various physical processes such as precipitation, evaporation, infrared radiation, convection, advection, and turbulence. — At the start of the 21st century, clouds represent the biggest source of uncertainty in our understanding of climate prediction since it is not yet clear whether clouds actually have the general effect of cooling or warming the Earth. This is because high altitude clouds warm the Earth while clouds lower in the atmosphere contribute to cooling.

Climate change. The long–term fluctuations in temperature, precipitation, wind, and all other aspects of the Earth’s climate. External processes, such as solar–irradiance variations, variations of the Earth’s orbital parameters (eccentricity, precession, and inclination), lithosphere motions, and volcanic activity, are factors in climatic variation. Internal variations of the climate, e.g., changes in the abundance of greenhouse gases, may also produce fluctuations of sufficient magnitude and variability to explain observed climate change through the feedback processes interrelating the components of the climate system.⁶⁸³⁴⁾

Climate change is one of the defining issues of our time. Climate change is not only indisputable, it’s largely the result of human activities. Areas of active debate include how much warming to expect in the future and the connections between climate change and extreme weather events such as the frequency and intensity of hurricanes, droughts and floods.⁶⁸³⁵⁾

Earth’s average surface air temperature has increased by about 0.8°C since 1900, and the last 30 years have been the warmest in 800 years. It’s the most rapid period of sustained temperature change in the scale of global history, trumping every ice age cycle.

Recent estimates of the increase in global temperature since the end of the last ice age are four to five degrees Celsius. While this is much greater than the 0.8° C change recorded over the last 100+ years, this change occurred over a period of about 7,000 years. So the change in rate is now 10 times faster.

Of course an increase in temperature goes hand in hand with an increase in carbon emissions. Greenhouse gases such as carbon dioxide absorb heat (infrared radiation) emitted from the Earth’s surface. Increases in the atmospheric concentrations of these gases trap most of the outgoing heat, causing the Earth to warm. Human activities, especially the burning of fossil fuels have increased carbon dioxide concentrations by 40 percent between 1880 and 2012. It is now higher than at any time in at least 800,000 years.

6833) Courtesy of W. Esaias of NASA/GSFC

6834) S. Weart, “The Discovery of Rapid Climate Change,” *Physics Today*, Aug. 2003, pp. 30–36

6835) Ralph J. Cicerone, Sir Paul Nurse, “Climate Change Evidence & Causes – An overview from the Royal Society and the US National Academy of Sciences,” Feb. 2014, URL: <http://dels.nas.edu/resources/static-assets/excc-office-other/climate-change-full.pdf>

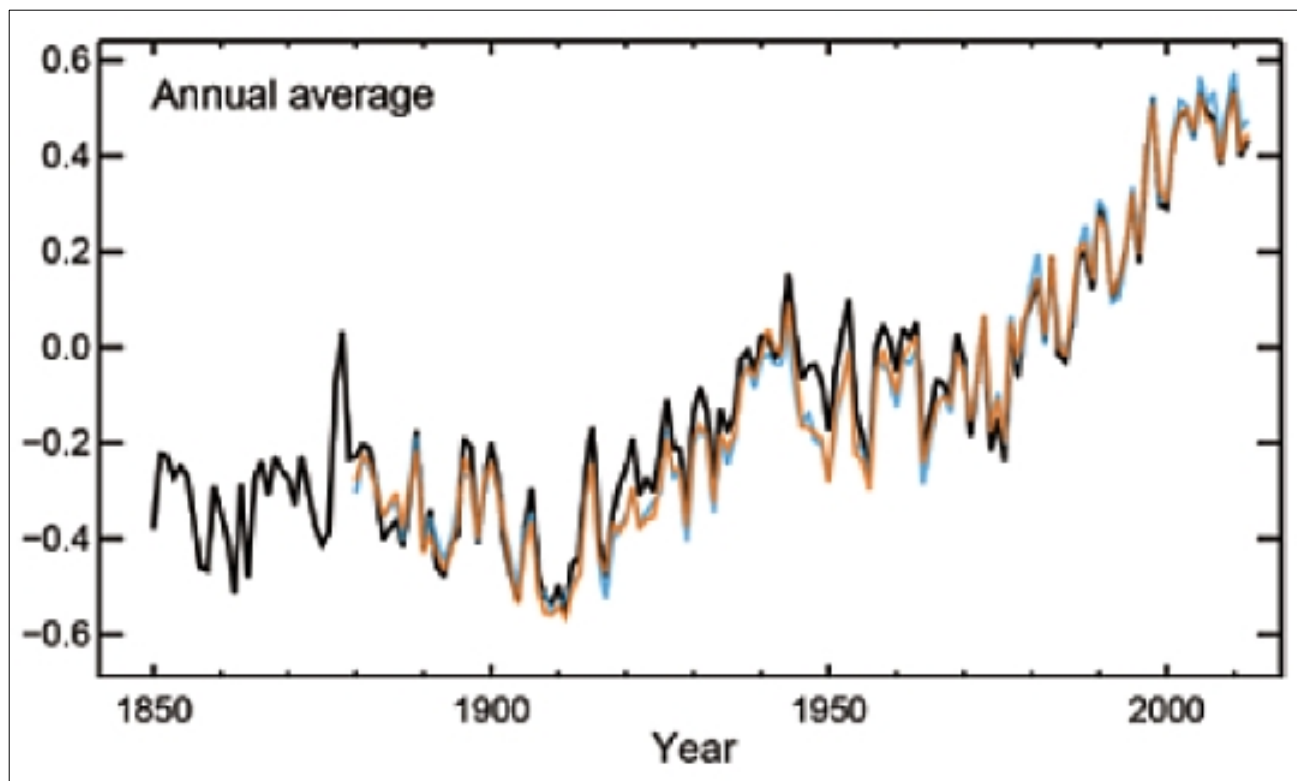


Figure 1572: Earth's global average surface temperature has risen as shown in this plot of combined land and ocean measurements from 1850 to 2012, derived from three independent analyses of the available data sets (image credit: National Academy of Sciences, The Royal Society)

Clouds. A visible mass of condensed water vapor particles or ice suspended above the Earth's surface. Clouds may be classified by their visual appearance, height, or form. Clouds typically cover about 60% of our planet. They have two contrary effects on the Earth's radiation budget. On one hand, they tend to cool the Earth by reflecting the light coming from the sun back into space. On the other hand, the cloud mantle keeps the surface warm by absorbing the upwelling radiance and reflecting it back to the ground. The properties of clouds can vary widely with location, with time of day, with changing weather and with season. Satellite observations are the most effective way to observe clouds on a large scale.

Cloud albedo. Reflectivity that varies from less than 10 to more than 90 percent of the insolation and depends on drop sizes, liquid water content, water vapor content, thickness of the cloud, and the sun's zenith angle. The smaller the drops and the greater the liquid water content, the greater the cloud albedo, if all other factors are the same.

Cloud feedback. The coupling between cloudiness and surface air temperature in which a change in surface temperature could lead to a change in clouds, which could then amplify or diminish the initial temperature perturbation. For example, an increase in surface temperature could increase evaporation; this in turn might increase the extent of cloud cover. Increased cloud cover would reduce the solar radiation reaching the Earth's surface, thereby lowering the surface temperature. This is an example of negative feedback and does not include the effects of longwave radiation or advection in the oceans and the atmosphere, which must also be considered in the overall relationships within the climate system.

Cloud microphysics. Study of cloud and precipitation particles (individual or populations) and their interactions with the environment. Of key importance are mass exchange processes such as nucleation, growth, and fallout leading to the broad characteristics of clouds and precipitation.

Code Division Multiple Access (CDMA). Refers to an access scheme which employs spread-spectrum modulations and orthogonal codes to share a communication link among

its users. In the CDMA scheme, all users transmit simultaneously and at the same frequency, with each being assigned a unique pseudorandom noise code. Usually, the data is first phase-modulated by a carrier and then the carrier is bi-phase-modulated with a pseudorandom noise (PNR) code. This concept generates a wide bandwidth, low-energy spread spectrum signal.

Coherence. A fixed relationship between the phases of waves in a beam of radiation of a single frequency. Two beams of light are coherent when the phase difference between their waves is constant; they are **noncoherent (or incoherent)** if there is a random phase relationship. In active measurement systems like radars, coherence refers to the availability of phase and amplitude measurements of the radar cross section of the recovered signals. Coherence provides the ability to maximize SNR and to measure other features like target radial velocity.

Coma. An off-axis aberration whereby the outer periphery of a lens system has a higher (or lower) magnification than the central portion of the lens. The image typically is comet shaped.

Contrast. The ratio of a certain quantity of radiation between the brightest and darkest part of an image or between two arbitrary places of an image, where the contrast is to be determined.

Convection (meteorology). Vertical wind motions and associated horizontal circulations associated with buoyancy.

Convolution. Mathematical process, appearing in linear or circular form, that models the input-output filtering process.

Convolution filter. A linear filter type as used in digital image processing of which the window operation has a mathematically linear character (weighted summation). Examples are low-pass filter, high-pass filter, gradient filters, Laplacian filters, etc.

Corona. Refers to the outer atmosphere of the sun whose structure is controlled by solar magnetic fields. The corona has temperatures between one and three million degrees. It merges into the solar wind at its upper boundary about 1–2 solar radii above the visible surface of the photosphere.

Coronagraph. A coronagraph is a telescope designed to block light coming from the solar disk, in order to see the extremely faint emission from the region around the sun, called the corona. It was invented in 1930 by Bernard Lyot (French astronomer) to study the sun's corona at times other than during a solar eclipse. The coronagraph, at its simplest, is an occulting disk in the focal plane of a telescope or out in front of the entrance aperture that blocks out the image of the solar disk, and various other features to reduce stray light so that the corona surrounding the occulting disk can be studied.

Coronal Mass Ejection (CME). CMEs are very large structures (billions of tons of particles, super hot hydrogen gas) containing plasma and magnetic fields that are expelled from the sun into the heliosphere at speeds of several hundred to over 1000 km/s. CMEs often drive interplanetary shock waves which, upon arrival at Earth (after a few days), may cause geomagnetic disturbances. Geomagnetic storms are a major component of the **space weather**. The geomagnetic storms that signify the arrival of a CME in near-Earth space pose hazards to all space operations. A major effect is the release of trapped particles from the magnetosphere into the auroral zones, causing increases in S/C charging, single-event upsets, and hazardous radiation dose rates for astronauts. Other effects include interference with satellite communication and surveillance systems. Atmospheric heating by charged particles results in increased satellite drag. Geomagnetic storms may also cause harm to the magnetic attitude control systems of S/C.

Note: CMEs are also referred to as solar flares.



Figure 1573: Image of a large solar flare (image credit: ESA, NASA)

Cosmic background radiation (CBR), also known as **CMB** (Cosmic Microwave Background) radiation. Refers to the faint isotropic (omnipresent) cosmic microwave background radiation at 2.725 K in the universe which peaks in the microwave range at a frequency of 160.2 GHz (wavelength of 1.9 mm). The discovery of cosmic background radiation occurred in 1965 by Arno Allen Penzias and his astronomer colleague Robert Woodrow Wilson at the Bell Laboratories in Holmdel, N. J. Their discovery has been used as evidence in support of the “big bang theory” that the universe was created by a giant explosion billions of years ago. Both scientists received the Nobel Prize in Physics in 1978 (along with Peter Kapitza). The scientists used the company’s radio astronomy antenna facilities for their research (they were testing a highly sensitive new type of radio telescope for communications). Because the signal was so faint and pervasive, the two scientists initially believed the noise could have come from any number of sources, including the antenna itself. No matter what direction they pointed their horn-shaped antenna – the signal persisted. The signal never wavered from day-to-day, season-to-season, thus marking itself as unique.

- March 21, 2013: Acquired by ESA’s Planck space telescope, the most detailed map ever created of the **CMB (Cosmic Microwave Background)** – the relic radiation from the Big Bang – was released today revealing the existence of features that challenge the foundations of our current understanding of the Universe.

The image (Figure 1574) is based on the initial 15.5 months of data from Planck and is the mission’s first all-sky picture of the oldest light in our Universe, imprinted on the sky when it was just 380 000 years old. The map results suggest the universe is expanding more slowly than scientists thought, and is 13.8 billion years old, 100 million years older than previous estimates. The data also show there is less dark energy and more matter, both normal and

dark matter, in the universe than previously known. Dark matter is an invisible substance that can only be seen through the effects of its gravity, while dark energy is pushing our universe apart. The nature of both remains mysterious. ^{6836) 6837) 6838)}

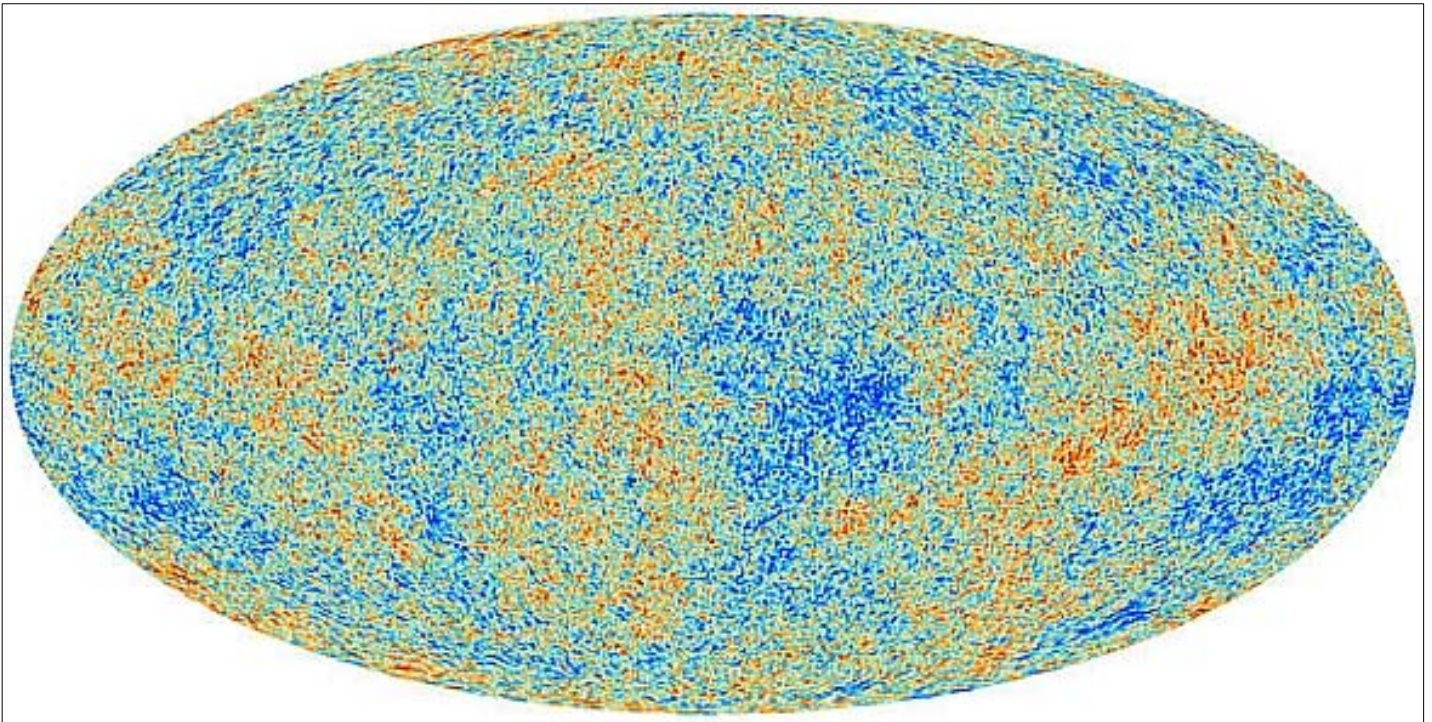


Figure 1574: The CMB (Cosmic Microwave Background) as seen by the Planck (image credit: ESA and the Planck Collaboration)

The Planck spacecraft was launched on May 14, 2009 to Lagrangian Point L2. Planck is an ESA mission. NASA contributed mission-enabling technology for both of Planck's science instruments, and U.S., European and Canadian scientists work together to analyze the Planck data. Planck was designed to map the sky in nine frequencies using two state-of-the-art instruments: the LFI (Low Frequency Instrument), which includes the frequency bands 30–70 GHz, and the HFI (High Frequency Instrument), which includes the frequency bands 100–857 GHz. – Planck's first all-sky image, including emissions from our own Milky Way galaxy, was presented in July 2010. The first scientific dataset was released in January 2011.

The young Universe (at age 380,000 years) was filled with a hot dense soup of interacting protons, electrons and photons at about 2700°C. When the protons and electrons joined to form hydrogen atoms, the light was set free. As the Universe has expanded, this light today has been stretched out to microwave wavelengths, equivalent to a temperature of just 2.7 degrees above absolute zero.

This 'cosmic microwave background' – CMB – shows tiny temperature fluctuations that correspond to regions of slightly different densities at very early times, representing the seeds of all future structure: the stars and galaxies of today.

6836) "Planck reveals an almost perfect Universe." ESA, March 21, 2013, URL: http://www.esa.int/Our_Activities/Space_Science/Planck/Planck_reveals_an_almost_perfect_Universe

6837) Jan Tauber, George Efstathiou, François R. Bouchet, Paolo Natoli, Krzysztof M. Górski, "Simple but challenging: The Universe according to Planck," ESA, March 21, 2013, URL: <http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=51551>

6838) "Planck mission brings Universe into sharp focus," NASA/JPL, March 21, 2013, URL: <http://planck.caltech.edu/news20130321.html>

Thanks to a supersensitive space telescope and some sophisticated supercomputing, scientists from the international Planck collaboration have made the closest reading yet of the most ancient story in our universe: the cosmic microwave background (CMB).⁶⁸³⁹⁾

- Feb. 5, 2015: New maps of ESA's uncover the polarized CMB data from the early Universe across the entire sky (Figure 1575), revealing that the first stars formed much later than previously thought. A small fraction of the CMB is polarized – it vibrates in a preferred direction. This is a result of the last encounter of this light with electrons, just before starting its cosmic journey. For this reason, the polarization of the CMB retains information about the distribution of matter in the early Universe, and its pattern on the sky follows that of the tiny fluctuations observed in the temperature of the CMB.⁶⁸⁴⁰⁾

In this image, the color scale represents temperature differences in the CMB, while the texture indicates the direction of the polarized light. The patterns seen in the texture are characteristic of 'E-mode' polarization, which is the dominant type for the CMB.

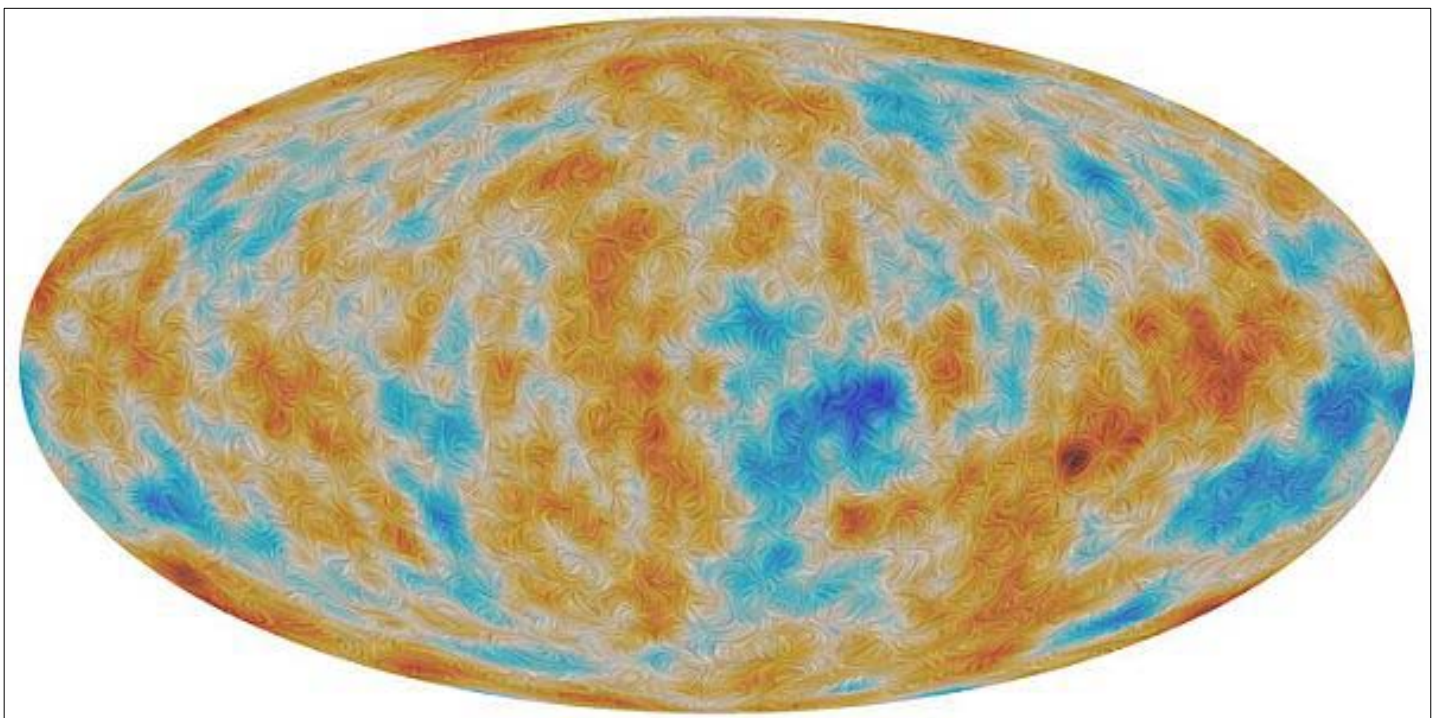


Figure 1575: A visualization of the polarization of the CMB, as detected by ESA's Planck satellite over the entire sky. (image credit: ESA and the Planck Collaboration)

Legend to Figure 1575: For the sake of illustration, both data sets have been filtered to show mostly the signal detected on scales around 5° on the sky. However, fluctuations in both the CMB temperature and polarization are present and were observed by Planck on much smaller angular scales, too.

- Sept. 11, 2016 — CMB continued: The standard Λ CDM (Adiabatic Cold Dark Matter) model of cosmology assumes the Copernican principle, which states that the Universe is isotropic and homogeneous on large scales.⁶⁸⁴¹⁾ ⁶⁸⁴²⁾ In this sense, there is no such thing as "up" or "down" when it comes to space, only points of reference that are entirely relative.

6839) "Building the Massive Simulation Sets Essential to Planck Results," Berkeley Lab, March 14, 2013, URL: <http://newscenter.lbl.gov/news-releases/2013/03/14/massive-planck-simulations/>

6840) "Polarization of the Cosmic Microwave Background," ESA, Feb. 5, 2015, URL: http://www.esa.int/spaceinimages/Images/2015/02/Polarisation_of_the_Cosmic_Microwave_Background

6841) Matt Williams, "Turns Out There Is No Actual Looking Up," Universe Today, Sept. 10, 2016, URL: <http://www.universetoday.com/130722/turns-no-actual-looking/>

6842) Daniela Saadeh, Stephen M. Feeney, Andrew Pontzen, Hiranya V. Peiris, Jason D. McEwen, "How isotropic is the Universe?," *Astrophysics*, Sept. 7, 2016, URL: <https://arxiv.org/pdf/1605.07178v2.pdf>

And thanks to a new study by researchers from the UCL (University College London), that view has been shown to be correct.

- The research team used survey data of the Cosmic Microwave Background (CMB) – the thermal radiation left over from the Big Bang. This data was obtained by the ESA’s Planck spacecraft between 2009 and 2013. The team then analyzed it using a supercomputer to determine if there were any polarization patterns that would indicate if space has a “preferred direction” of expansion. The purpose of this test was to see if one of the basic assumptions that underlies the most widely–accepted cosmological model is in fact correct. The first of these assumptions is that the Universe was created by the Big Bang, which is based on the discovery that the Universe is in a state of expansion, and the discovery of the Cosmic Microwave Background. The second assumption is that space is homogenous and isotropic, meaning that there are no major differences in the distribution of matter over large scales. This belief, which is also known as the Cosmological Principle, is based partly on the Copernican Principle (which states that Earth has no special place in the Universe) and Einstein’s Theory of Relativity – which demonstrated that the measurement of inertia in any system is relative to the observer. This theory has always had its limitations, as matter is clearly not evenly distributed at smaller scales (i.e. star systems, galaxies, galaxy clusters, etc.). However, cosmologists have argued around this by saying that fluctuation on the small scale are due to quantum fluctuations that occurred in the early Universe, and that the large–scale structure is one of homogeneity. By looking for fluctuations in the oldest light in the Universe, scientists have been attempting to determine if this is in fact correct. In the past thirty years, these kinds of measurements have been performed by multiple missions, such as the COBE (Cosmic Background Explorer) mission, the WMAP (Wilkinson Microwave Anisotropy Probe), and the Planck spacecraft. For the sake of their study, the UCL research team – led by Daniela Saadeh and Stephen Feeney – looked at things a little differently. Instead of searching for imbalances in the microwave background, they looked for signs that space could have a preferred direction of expansion, and how these might imprint themselves on the CMB.

- Basically, their results showed that there is only a 1 in 121 000 chance that the Universe is anisotropic. In other words, the evidence indicates that the Universe has been expanding in all directions uniformly, thus removing any doubts about their being any actual sense of direction on the large–scale.

- **Dark Matter:** Dark matter is non–luminous matter in the universe that is extremely difficult to be directly detected by observing any form of electromagnetic radiation, but whose existence is suggested by physics because of the effects of its gravity on the rotation rate of galaxies and the presence of clusters of galaxies. ⁶⁸⁴³⁾

Astronomers and cosmologists know that dark matter exists but as yet do not know what it is composed of or how much of it there actually is. There are many candidates for dark matter, including undetected brown dwarf stars, white dwarf stars, black holes, or neutrinos with mass (neutrino, fundamental nuclear particle that is electrically neutral and of much smaller mass, if any at all, than an electron), or indeed exotic subatomic particles, such as WIMPs (Weakly Interacting Massive Particles) or MACHOs (MASSive Compact Halo Objects). Physicists are currently searching for such particles in underground laboratories (to prevent interference) and ways to detect them.

- April 02, 2013: **All–sky image of dark matter distribution (Figure 1576):** Cosmologists using data from ESA’s Planck satellite have compiled the first all–sky image of the distribution of dark matter across the entire history of the Universe as seen projected on the sky. This is made possible by analyzing the tiny distortions imprinted on the photons of the CMB (Cosmic Microwave Background) by the **gravitational lensing effect of massive cos-**

⁶⁸⁴³⁾ “Dark Matter and its implications,” Astronomy Today, URL: http://www.astronomytoday.com/cosmology/dark_matter.html

mic structures. As photons travelled through these structures, which consist primarily of dark matter, their paths became bent, slightly changing the pattern of the CMB. Although noisy, this image is the first measurement performed over almost the whole sky of the gravitational potential that distorts the CMB, and is one of the highlights of Planck's cosmological results. With these unique data, cosmologists can investigate 13 billion years of the formation of structure in the Universe. The data agree very well with the expectations from the leading cosmological model that describes the origin and evolution of cosmic structure in the Universe. ⁶⁸⁴⁴⁾

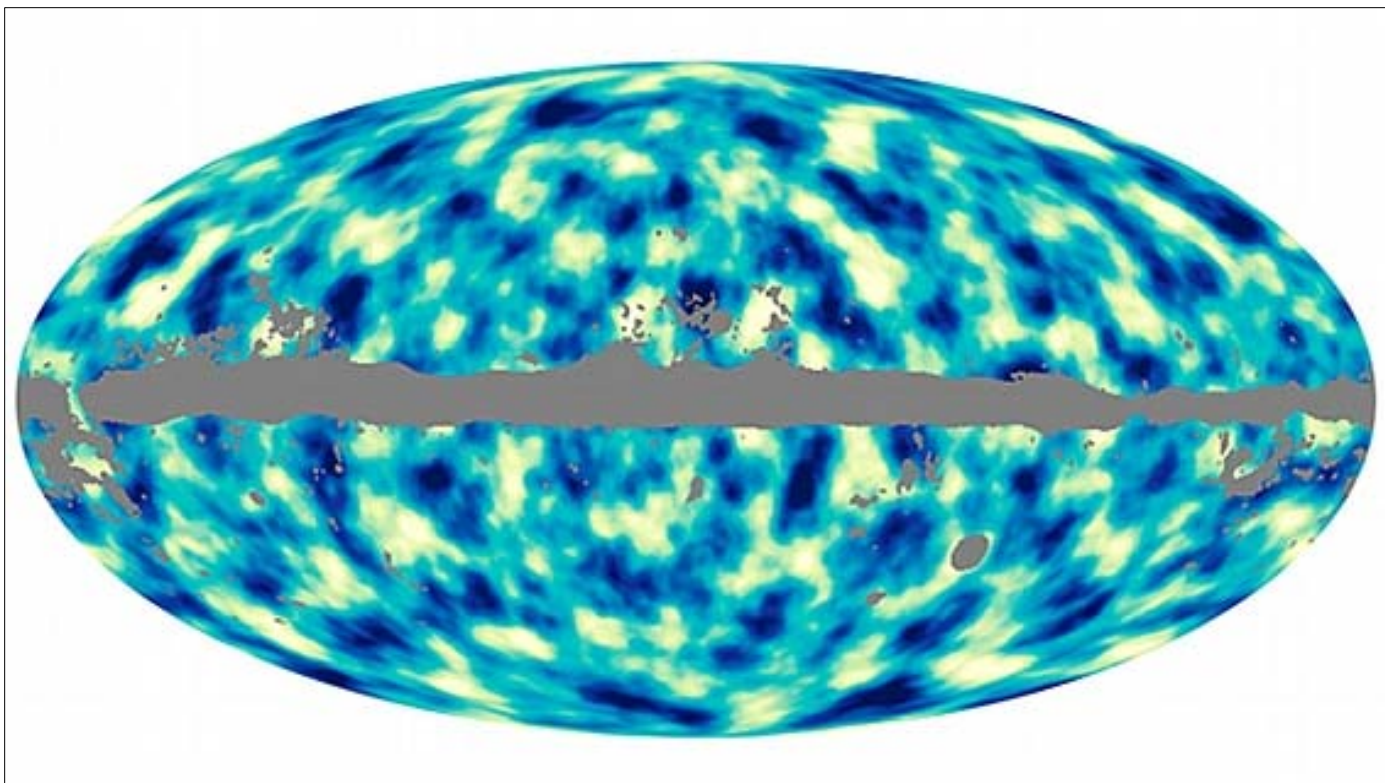


Figure 1576: All-sky map of dark matter distribution in the Universe (image credit: ESA and the Planck Collaboration)

This all-sky image (Figure 1576) shows the distribution of dark matter across the entire history of the Universe as seen projected on the sky. It is based on data collected with ESA's Planck satellite during its first 15.5 months of observations. Dark blue areas represent regions that are denser than the surroundings, and bright areas represent less dense regions. The grey portions of the image correspond to patches of the sky where foreground emission, mainly from the Milky Way but also from nearby galaxies, is too bright, preventing cosmologists from fully exploiting the data in those areas.

The reconstruction technique used to compile this image relies on deviations of the shapes of hot and cold spots in the CMB from their 'typical' shape, and it is impossible to avoid the introduction of statistical 'noise' in the reconstruction; approximately half of the modes in this image are due to this noise.

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⁶⁸⁴⁴⁾ ESA and the Planck Collaboration, "All-sky map of dark matter distribution in the universe," ESA, April 2, 2013, URL: <http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=51604>

- Dec. 15, 2014: The latest data from ESA's Planck mission suggests that the mysterious substance comprises 26.2% of the cosmos, making it nearly five and a half times more prevalent than normal, everyday matter. Now, four European researchers have hinted that they may have a discovery on their hands: a signal in X-ray that has no known cause, and may be evidence of a long sought-after interaction between particles – namely, the annihilation of dark matter. ^{6845) 6846)}

- Earlier this year, researchers at the Laboratory of Particle Physics and Cosmology (LP-PC) in Switzerland and Leiden University in the Netherlands identified an excess bump of energy in X-ray radiation coming from both the Andromeda galaxy and the Perseus star cluster: an emission line with an energy around 3.5 keV. No known process can account for this line; however, it is consistent with models of the theoretical sterile neutrino – a particle that many scientists believe is a prime candidate for dark matter. — The researchers believe that this strange emission line could result from the annihilation, or decay, of these dark matter particles, a process that is thought to release x-ray photons. In fact, the signal appeared to be strongest in the most dense regions of Andromeda and Perseus and increasingly more diffuse away from the center, a distribution that is also characteristic of dark matter.

Cosmic dust. A slow, steady rain of cosmic space dust is always falling through the Earth's atmosphere. These particles from space are infused with a rare isotope of helium that makes it immediately identifiable compared to a more common isotope of helium we find here on Earth. Scientists recently drilled an ice core in Antarctica containing a record of this dust fall that goes back 30,000 years. This new data (2006) gives scientists another line of data to study global climate history as the ratio between the isotopes varies between interglacial periods. ⁶⁸⁴⁷⁾

Cosmic rays. An incoming ultrahigh-energy radiation [with nucleon energies ranging from ≤ 1 MeV to $> EeV$ (Exa = 10^{18}) and higher] of sub-atomic particles that have been accelerated close to the speed of light. ⁶⁸⁴⁸⁾ Cosmic rays with energies $< 10^{15}$ eV (or PeV) are believed to have been accelerated in supernovae remnants in our galaxy. Cosmic rays with energies $> 10^{15}$ eV are of extragalactic origin. Generally, cosmic rays do not penetrate Earth's atmosphere, but they may produce a shower of secondary particles that penetrate the Earth's upper atmosphere, producing Cherenkov radiation in the process. An infrequent shower of cosmic rays can be detected by arrays of scintillators on the ground; they also announce their presence by producing a trail of ultraviolet fluorescent light, exciting the nitrogen atoms in the atmosphere. The existence of such showers has been known since 1963.

Astronauts have long reported the experience of seeing flashes while they are in space, even when their eyes are closed. Neil Armstrong and Buzz Aldrin both reported these flashes during the Apollo 11 mission, and similar reports during the Apollo 12 and 13 missions led to subsequent Apollo missions including experiments specifically looking at this strange phenomenon. These experiments involved blindfolding crewmembers and recording their comments during designated observation sessions, and later missions had a special device, the ALFMED (Apollo Light Flash Moving Emulsion Detector), which was worn by the as-

6845) A. Boyarsky, O. Ruchayskiy, D. Iakubovskiy, J. Franse, "Unidentified Line in X-Ray Spectra of the Andromeda Galaxy and Perseus Galaxy Cluster," *Physical Review Letters*, Vol. 113, 251301, 15 December 2014

6846) Vanessa Janek, "New Signal May Be Evidence of Dark Matter, Say Researchers," *Universe Today*, Dec. 15, 2014, URL: <http://www.universetoday.com/117295/new-signal-may-be-evidence-of-dark-matter-say-researchers/>

6847) <http://www.universetoday.com/2006/08/07/constant-rain-of-space-dust-adds-up/>

6848) F. W. Stecker, "The Curious Adventure of the Ultrahigh Energy Cosmic Rays," *Astrophysics abstracts* (astro-ph/0101072), Jan. 11, 2001, URL: <http://owl.gsfc.nasa.gov/stecker01.pdf>

tronauts during dark periods to record of incidents of cosmic ray hits. ⁶⁸⁴⁹⁾

The origin of cosmic rays has been one of the most enduring mysteries in physics, and it looks like it's going to stay that way for a while longer. One of the leading candidates for where cosmic rays come from is gamma ray bursts, and physicists were hoping a huge Antarctic detector called the IceCube Neutrino Observatory would confirm that theory. But observations of over 300 GRB's turned up no evidence of cosmic rays. In short, cosmic rays aren't what we thought they were. ⁶⁸⁵⁰⁾

Crossover (difference). A crossover is defined as the intersection points of the satellite ground track with itself (due to Earth rotation). At this location, the two crossing passes (one ascending and one descending) provide independent subsatellite ground track measurements at the same location but at different times. In altimetry, crossover differences contain information about uncertainties in the satellite ephemeris and therefore enable correction of radial orbit error.

Crossover point. Refers to radar measurements concerning the curves showing the dependency of the radar backscatter behavior on the incidence angle of the radar transmission signals onto surfaces of differing roughness. The crossover point is the incidence angle where the diffuse region changes into a specular region on the curves (or: the incidence angle where the effect of soil roughness vanishes and the radar backscatter value is determined by the presence of soil moisture).

Cryosphere (from the Greek word 'kryos', frost or icy cold). The cryosphere collectively describes frozen water in the Earth System. As an integral part of the global climate system, it influences surface energy, moisture, gas and particle fluxes, clouds, precipitation, hydrology, and atmospheric and oceanic circulation. The Earth's cryosphere consists of four main elements: sea ice, seasonal snow on land, land ice (including glaciers, ice sheets, and ice shelves), and permafrost. The time scales on which these elements impact human activity range from daily to seasonal for sea ice and snow, while ice shelves respond in the range of 10–100 years, ice sheets (Antarctic and Greenland) have periods in the order of 1000–10,000 years. Land ice occupies about 11% of the continental surfaces. Sea ice and ice shelves spread around 7% of the total oceanic area.

The cryosphere plays an integral part in all other Earth system components because of the high shortwave reflectivity of snow and ice, and because of all the freshwater locked up as ice (almost 80% of the freshwater on Earth). It has a strong influence on the surface energy and moisture fluxes, precipitation, hydrology, sea-level rise and atmospheric and ocean circulation. The freshwater provided by the melting of glaciers and land ice sheets is responsible for an increase in sea levels of 18 cm during the last century.

6849) Nancy Atkinson, "'Seeing' Cosmic Rays in Space," Universe Today, April 19, 2012, URL: <http://www.universetoday.com/94714/seeing-cosmic-rays-in-space/>

6850) Nancy Atkinson, "Cosmic Rays: They Aren't What We Thought They Were," Universe Today, April 19, 2012, URL: <http://www.universetoday.com/94703/cosmic-rays-they-arent-what-we-thought-they-were/>

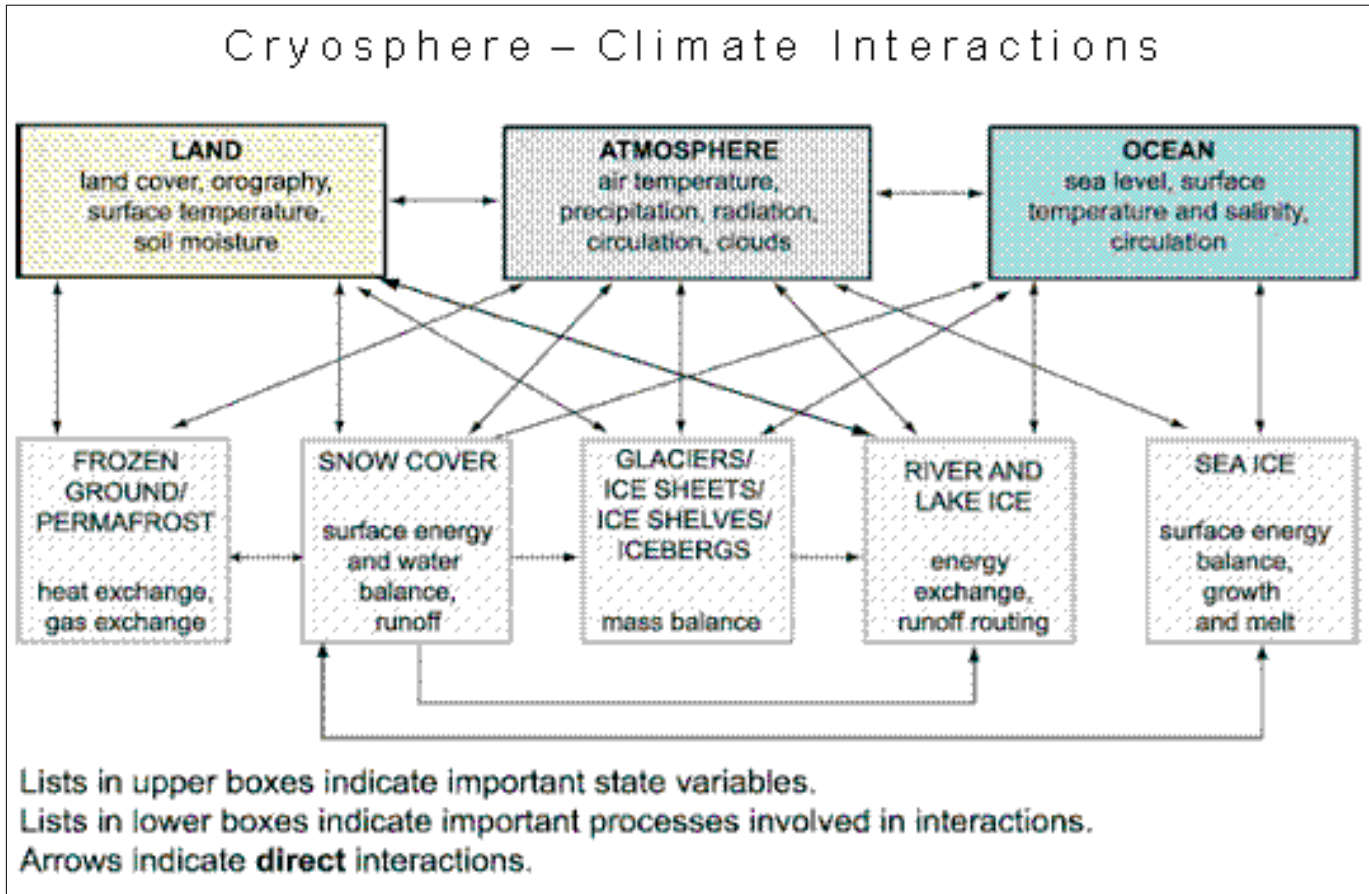


Figure 1577: Schematic of cryosphere–climate interactions (image credit: University of Wisconsin)

Cryosphere impact on the environment: In September 2013, a very interesting result of a far–reaching impact on Earth’s environment was reported in a NASA study. A team of researchers uncovered strong evidence that soot from a rapidly industrializing Europe caused the abrupt retreat of mountain glaciers in the European Alps that began in the 1860s, a period often thought of as the end of the Little Ice Age. – In the decades following the 1850s, Europe underwent an economic and atmospheric transformation spurred by industrialization. The use of coal to heat homes and power transportation and industry in Western Europe began in earnest, spewing huge quantities of black carbon and other dark particles into the atmosphere. ^{6851) 6852)}

Black carbon is the strongest sunlight–absorbing atmospheric particle. When these particles settle on the snow blanketing glaciers, they darken the snow surface, speeding its melting and exposing the underlying glacier ice to sunlight and warmer spring and summer air earlier in the year. This diminishing of the snow cover earlier in each year causes the glacier ice to melt faster and retreat.

The Little Ice Age, loosely defined as a cooler period between the 14th and 19th centuries, was marked by an expansion of mountain glaciers and a drop in temperatures in Europe of nearly 1°C. But glacier records show that between 1860 and 1930, while temperatures continued to drop, large valley glaciers in the Alps abruptly retreated by an average of nearly 1 km to lengths not seen in the previous few hundred years. Glaciologists and climatologists have struggled to reconcile this apparent conflict between climate and glacier records.

6851) Tony Phillips, “Industrial Soot Linked to the Retreat of 19th Century Glaciers,” NASA, Sept. 4, 2013, URL: http://science.nasa.gov/science–news/science–at–nasa/2013/03sep_oot/

6852) Thomas H. Painter, Mark G. Flanner, Georg Kaser, Ben Marzeion, Richard A. VanCuren, Waleed Abdalati, “End of the Little Ice Age in the Alps forced by industrial black carbon,” PNAS (Proceedings of the National Academy of Sciences), Sept. 3, 2013, Abstract, URL: <http://www.pnas.org/content/early/2013/08/28/1302570110>

The team then ran computer models of glacier behavior, starting with recorded weather conditions and adding the impact of the lower-elevation pollution. When this impact was included, the simulated glacier mass loss and timing finally were consistent with the historic record of glacial retreat, despite the cooling temperatures at that time.

Decibel (dB) – named in honor of Alexander Graham Bell. A measurement of signal strength, properly applied to a ratio of powers. For the signal power P compared by a ratio to a reference power P_{ref} , the definition is: $P_{\text{db}} = 10\log_{10} (P/P_{\text{ref}})$. As an example, the power ratio of 1/2 corresponds to “3 dB”, derived from: $\log_{10} (0.5) = -0.3010$.

Detectivity (D^*). A parameter used to compare the performance of different detector types. D^* is the signal-to-noise ratio (SNR) at a particular electrical frequency and in a 1 Hz bandwidth when 1 Watt of radiant power is incident on a 1 cm² active area detector. The higher D^* the better the detector. D^* is normally expressed either as a blackbody D^* or as a peak wavelength D^* within the practical operating frequency of the detector. The units of D^* are centimeter-square root hertz per watt.

Deep Space Highway: As of March 2017, a NASA concept for a habitable platform in the vicinity of the moon, known as cislunar space. Payloads and astronauts could be sent to the gateway starting in the 2020s using the heavy-lift SLS (Space Launch System) rocket and the Orion crew vehicle, both of which are still under development. The gateway would be a crew-tended spaceport with a high-power electric propulsion system.⁶⁸⁵³⁾

Deforestation. The removal of forest stands by cutting and burning to provide land for agricultural purposes, residential or industrial building sites, roads, etc., or by harvesting the trees for building materials or fuel. Oxidation of organic matter releases CO₂ to the atmosphere, with possible regional and global impacts.

Densimeter. A photometer designed for measuring the optical density of a material, generally a photographic image by visual or photoelectric effects.

Depolarization ratio. The ratio of intensities of light scattered perpendicular and parallel to the E-vector of the incident radiation.

Detector. A device that detects and linearly transduces radiative power into an electrical signal. Direct detectors may be categorized as photon detectors (an electrical signal is produced by free charges on the detector surface from the incident photons) or thermal detectors (an electrical signal is produced due to the temperature change). Detectors may also be classified according to their arrangement: single line detectors, array detectors. Thermal detectors usually require cooling (active or passive). Infrared radiation is ‘thermal’ by nature, hence the detector is affected by the medium that is measured. As a rule of thumb, the longer the IR wavelength that is to be measured, the colder the detector must be. In the VNIR region the detector element temperatures rarely need to be below 200 K. From 1–17 μm, temperatures are typically in the range 50–80 K. The longer wavelengths of the microwave region usually demand temperatures below 20 K. The detectivity of a cooled detector is much higher than one operating at room temperature. The noise contribution from background radiation at 300 K is several orders of magnitude higher than that of the 4 K surroundings of the detector (see Q.4).

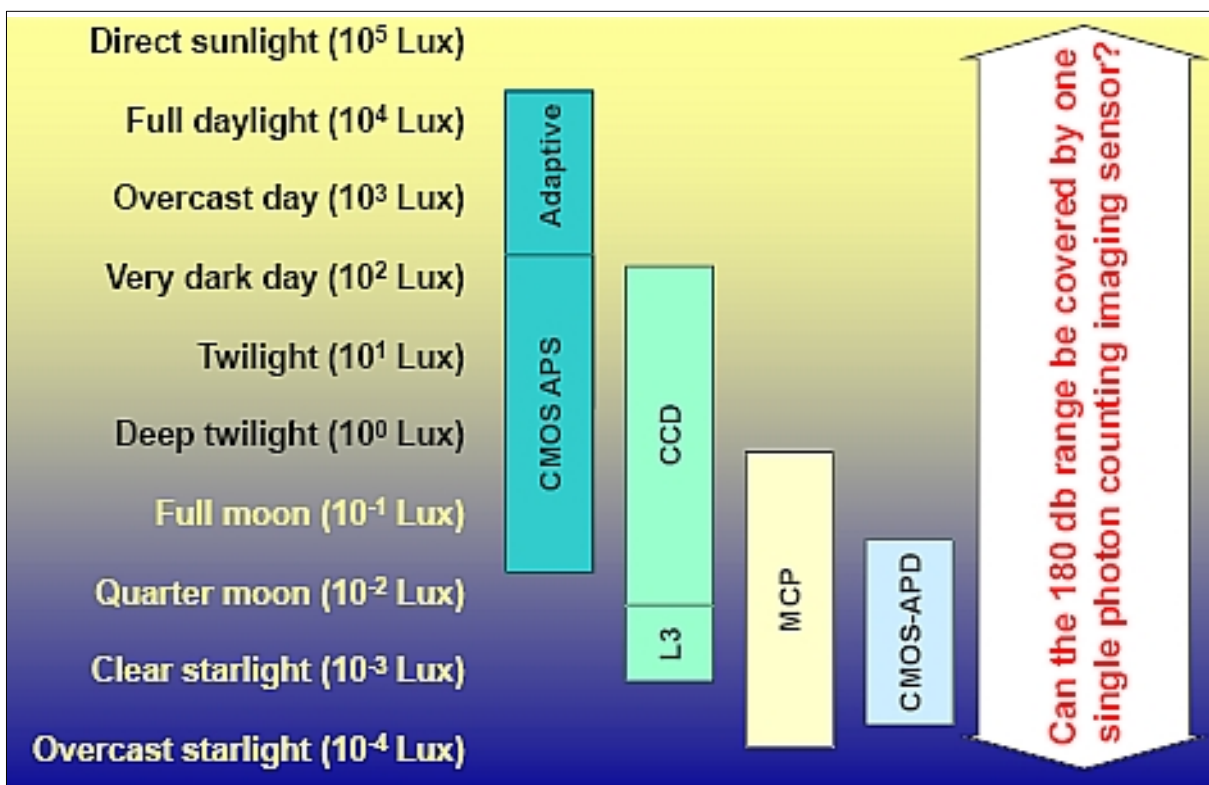
Detector types for spectral ranges.⁶⁸⁵⁴⁾ From the UV to VNIR (0.3–1 μm), silicon photodiodes and photoemissive devices such as photomultiplier tube (PMT) are normally used. Between 1–12 μm, two technologies dominate: InSb (indium antimonide) from 1–5.5 μm, and HgCdTe (mercury cadmium telluride, also referred to as MCT). Both, InSb and MCT operate in a photovoltaic mode. For the spectral range of 12–35 μm, photoconductors or

6853) “Deep Space Gateway to Open Opportunities for Distant Destinations,” NASA, March 28, 2017, URL: <https://www.nasa.gov/feature/deep-space-gateway-to-open-opportunities-for-distant-destinations>

6854) R. Beer, “Remote Sensing by Fourier Transform Spectrometry,” John Wiley & Sons, Inc., New York, 1992, Chapter 4.1.2

MCT are being used. Beyond 30 μm , the only available technology in use is the semiconductor bolometer (bolometer detectors are energy–balancing devices).⁶⁸⁵⁵⁾

- A photomultiplier tube (**PMT**) is a sensitive radiation detector for low intensity applications (spectral range from EUV to NIR or from 0.1 to 1.1 μm). A PMT consists of a photoemissive cathode, a series of electrodes (dynodes), and an anode sealed within a common evacuated envelope. Photons that strike the cathode emit electrons due to the photoelectric effect. Voltages applied to the cathodes, dynodes, and anode cause electrons that are ejected from the photoemissive cathode to make collisions with the dynodes in succession, knocking out more electrons at each collision. In this arrangement the dynodes provide signal amplification up to factors of 10^6 . The amplified signal is taken off the anode.
- Microchannel plate (**MCP**). A detector system, covering the spectral range from UV to x–ray and to gamma–rays and particles, employing large–area electron multipliers that provide spatial resolution as well as amplification. Depending on requirements MCPs may be coupled with a scintillator, a film, or a CCD array to provide imaging in the spectral range. MCPs consist of a matrix of hollow glass tubes. The hole diameter and spacing is typically 5–50 μm . The surface of a plate is usually coated with a photocathode material, while the interior of the holes is coated with a material of a high secondary emission coefficient. MCPs are used for plasma particle, ion, photon, and/or electron counting applications (measurement of ionospheric fluxes in the solar wind, etc.). They exhibit a high count–rate capability; a stack of two or more MCPs allow ray–tracing for angular measurements (position–sensitive). Among photomultiplier detectors of single photons, MCPs have the best intrinsic detector resolution, in the order of 20 ps. The detection efficiency of a microchannel plate for photons is a function of the angle of incidence and photon energy.



6855) Note: Silicon is transparent in the spectral ranges of 1.4 – 7 μm and from 25 μm to well beyond 100 μm

Figure 1578: State-of-the-art single photon counting imaging (image credit: UCLA) ⁶⁸⁵⁶

- **Avalanche Photodiode (APD).** These are photodetectors that can be regarded as the semiconductor analog to photomultipliers (PMTs). By applying a high reverse bias voltage (typically 100–200 V in silicon), APDs show an internal current gain effect (around 100) due to impact ionization (avalanche effect). However, some silicon APDs employ alternative doping and beveling techniques compared to traditional APDs that allow greater voltage to be applied (> 1500 V) before breakdown is reached and hence a greater operating gain (> 1000). In general, the higher the reverse voltage the higher the gain. – A typical application for APDs is laser range finders and long range fiber optic telecommunication. New applications include positron emission tomography and particle physics. APDs are widely used in instrumentation and aerospace applications, offering a combination of high speed and high sensitivity unmatched by PIN [Positive Insulator Negative (diode)] detectors, and quantum efficiencies at > 400 nm unmatched by PMTs.

Dewar [after Sir James Dewar (1854–1928) a Scottish chemist and physicist]. The term denotes a vessel to store hot or cold substances over long periods of time. It is a container with at least two walls and a space between the walls evacuated so as to prevent the transfer of heat. There are various techniques in use for minimizing the heat transfer in spaceflight for liquid helium, like: multilayer insulation, multiple reflective surfaces in vacuum, vapor-cooled shields, passive orbital disconnect struts, etc.

Dielectric. An insulating material or a very poor conductor of electric current. When dielectrics are placed into an electric field, practically no current flows in them because, unlike metals, they have no loosely bound, or free, electrons that may drift through the material. Instead, electric polarization occurs, reducing the electric field within the dielectric. A vacuum is the only perfect dielectric. – A dielectric gas is a nonconductor of electricity to high applied electrical stress; a gas with a high breakdown voltage.

Dielectric constant. A property of an insulating material (a dielectric) equal to the ratio of the capacitance of the capacitor filled with the given material to the capacitance of an identical capacitor in a vacuum without the dielectric material ($\kappa = C/C_0$). – The soil dielectric constant, for instance, is determined largely by the soil physical properties, and is a function of the individual dielectric constants of the soil components (i.e. air, water, rock, etc.). The dielectric constant of the rock (soil) fraction is determined by factors such as temperature, salinity, soil textural composition, and sensor frequency. **Soil moisture** is a key land surface parameter in many Earth science disciplines.

Diffraction. A process by which the direction of radiation is changed so that it spreads into the geometric shadow region of an opaque or refractive object that lies in a radiation field. Diffraction is an optical “edge effect,” (differing only in degree from scattering) caused by particles with diameters of the same order of magnitude as, or larger than, the wavelength of radiation; scattering is caused by smaller objects. Diffraction causes a modification which light undergoes in passing by the edges of opaque bodies or through narrow slits or in being reflected from ruled surfaces, and in which the rays appear to be deflected producing fringes of parallel light and dark or colored bands.

Under ideal circumstances, the resolution of an optical system is limited by the diffraction of light waves. This so-called **diffraction limit** is generally described by the following angle (α) calculated using the light’s wavelength (λ) and optical system’s pupil diameter (D, or the effective aperture of the optics):

$$\sin \alpha = 1.22 \lambda/D \text{ (Rayleigh formula)}$$

⁶⁸⁵⁶) Kang L. Wang, Xinyu Zheng, “Towards Ultimate Single Photon Counting Imaging,” Workshop on CMOS Applications in Astronomy and Space Sciences, National Tsing Hua University, Hsinchu, Taiwan, Jan. 5–6, 2011, URL: http://crab0.astr.nthu.edu.tw/CMOS-workshop-2011/0105/0105_1540-1720_KIWang_TowardsUltimateSinglePhotonCountingImaging.pdf

Note that the diffraction limit (i.e. resolution) improves in proportion to the aperture diameter.

Diffraction grating. A system of close equidistant and parallel lines or bars (also grooves) on a polished surface used for producing spectra by diffraction.

Diffraction–limited system. An optical system in which aberrations are negligible with respect to diffraction effects.

Diffuse radiation. Radiation propagating in many different directions through a given small volume of space (converse is ‘specular radiation’). The ideal form of diffuse radiation is isotropic radiation (uniform radiation in all directions).

Digital count. Refers to the total number of pixels occurring in an image for each possible data value.

Digital Earth. A vision/initiative of Vice President Al Gore, presented in a speech at the California Science Center in Los Angeles, on Jan. 31, 1998.⁶⁸⁵⁷⁾ The proposed concept model of “Digital Earth” refers to a multi–resolution, 3–D representation of Earth, into which geo–referenced data can be embedded. A “Digital Earth” could, for instance, provide a mechanism for users to navigate and search for geospatial information, etc. – Obviously, such an objective is so vast, that no one organization in government, industry or academia could undertake such a project. A vast standards infrastructure is needed to make it happen! The benefits of such a seamless system are apparent to the entire Earth Observation community.

Digital filter. A digital device (or a mathematical procedure) capable of altering the magnitude, frequency or phase response of a digitally encoded input signal (it may also selectively transmit digital signals).

Digital Terrain Model (DTM). Refers to a land surface represented in digital form by an elevation grid or tables of three–dimensional coordinates to form surface contours. The DTM definition is identical to that of a **DEM** (Digital Elevation Model). A DTM or DEM forms the basic building block for combining other data for analysis. For instance, digitized spatial data (images) can be draped onto a DEM and analyzed using a GIS. The quality of such a DEM depends on the spatial resolution (in particular the topographic accuracy) of image data available. Interferometric SAR data and/or altimeter data are currently the best sources for DEM generation.

DEMs are being used in all kinds of geo–scientific disciplines, e.g. in geology, where the shape of the Earth surface is of interest, and in hydrology for modelling water runoff. Surface deformation measurements are indispensable for earthquake and volcano research. In contrast to isolated ground measurements, **DInSAR** (Differential Interferometric SAR) data give a full map of the motion and, thus, reveal the shape of the deformation pattern. **DInSAR** measurements of glacier motion, for instance, are used extensively by glaciologists.

Digitization. Refers to the process of converting an image into a discrete array of numbers. The array is called a digital image, its elements are called pixels (short for picture elements), and their values are called gray levels. Digitization involves two processes: sampling the image value at a discrete grid of points, and quantizing the value at each of these points to make it one of a discrete set of gray levels.

Diode. A semiconductor diode consists of a crystal (two terminals), part of which is n–type (negative charge) and part p–type (positive charge). The boundary between the two parts is called a p–n junction. There is a population of holes on the p–type side of the junction and a population of electrons on the n–type side. The p–n junction of the diode conducts cur-

⁶⁸⁵⁷⁾ G. W. Fuller, “A Vision for a Global Geospatial Information Network (GGIN) Creating, Maintaining and Using Globally Distributed Geographic Data, Information, Knowledge and Services,” *ASPRS*, May 1999, pp. 524–538

rent with one polarity of applied voltage but not with the other polarity. Rectification (current flow only in one direction) is a very important characteristic of the p–n junction. Another characteristic of the p–n junction is its direct conversion capability of radiant energy into electrical energy (optoelectronic effect).⁶⁸⁵⁸⁾ An incident photon, striking a p–n junction, has the same effect as a hole (positive charge); it is absorbed thereby creating electron–hole pairs. The resulting current can be detected (see **photodiode**).

Dipole. An electric system composed of two equal charges of opposite sign, separated by a finite distance; e.g. the nucleus and orbital electron of a hydrogen atom. An ordinary bar magnet is a magnetic dipole.

Dipole antenna. A type of array consisting of a system of dipoles. A dipole antenna differs from a dish antenna in that it consists of many separate antennas that collect energy by feeding all their weak individual signals into one common receiving set.

Discrete Fourier Transform. A mathematical method of transforming a time series into a set of harmonics in the frequency domain and vice versa.

Dispersion of spectra. The following methods are used to separate radiation (light) into its component spectra (colors):

- Refraction. Historically, prisms were first used to break up or disperse light into its component colors. The path of a light ray bends (refracts) when it passes through the prism, i.e. from one transparent medium to another (from air to glass).
- Diffraction. Diffraction gratings are composed of closely spaced transmitting slits on a flat surface or alternate reflecting and non–reflecting grooves. – In any grating spectrometer, if a slit aperture is moved along the surface where the spectral lines are focussed, the lines are transmitted successively through the aperture.
- Interference. An interferometer divides a wave front by semitransparent surfaces. This allows the beams to travel different paths. The beams are then recombined generating interference patterns.
- AOTF (Acousto–Optic Tunable Filter). The AOTF principle is based on acoustic diffractions of light in an anisotropic medium. An AOTF device consists of a piezoelectric transducer bonded to a birefringent crystal. When the transducer is excited by an applied RF signal, acoustic waves are generated in the medium. The propagating acoustic wave produces a periodic modulation of the index of refraction. This provides a moving phase grating that, under proper conditions, will diffract portions of an incident beam. – In operation, acousto–optic tunable filters resemble interference filters and can replace a filter wheel, grating, or prism in many applications (see Q.4.5).

Diurnal cycle (Lat. diurnalis). A 24–hour (daily) cycle associated with solar heating during the day and radiative cooling during the night. A periodic cycle affecting nearly all meteorological variables.

Doppler effect (after Christian J. Doppler, Austrian physicist, 1803–1853). The alteration in frequency of a wave of radiation caused by relative motion between the observer and the source of radiation.— The acoustic Doppler effect applies to the propagation of source waves; the optical Doppler effect depends on the relative velocity of the light source and the observer; the thermal Doppler effect causes a widening of the spectral lines.

⁶⁸⁵⁸⁾ Note: The term “hole” refers to a fictitious particle which carries a positive charge and moves, under the influence of an applied electric field (bias), in a direction opposite to that of an electron. The motion of electrons and holes in semiconductors is governed by the theory of quantum mechanics.

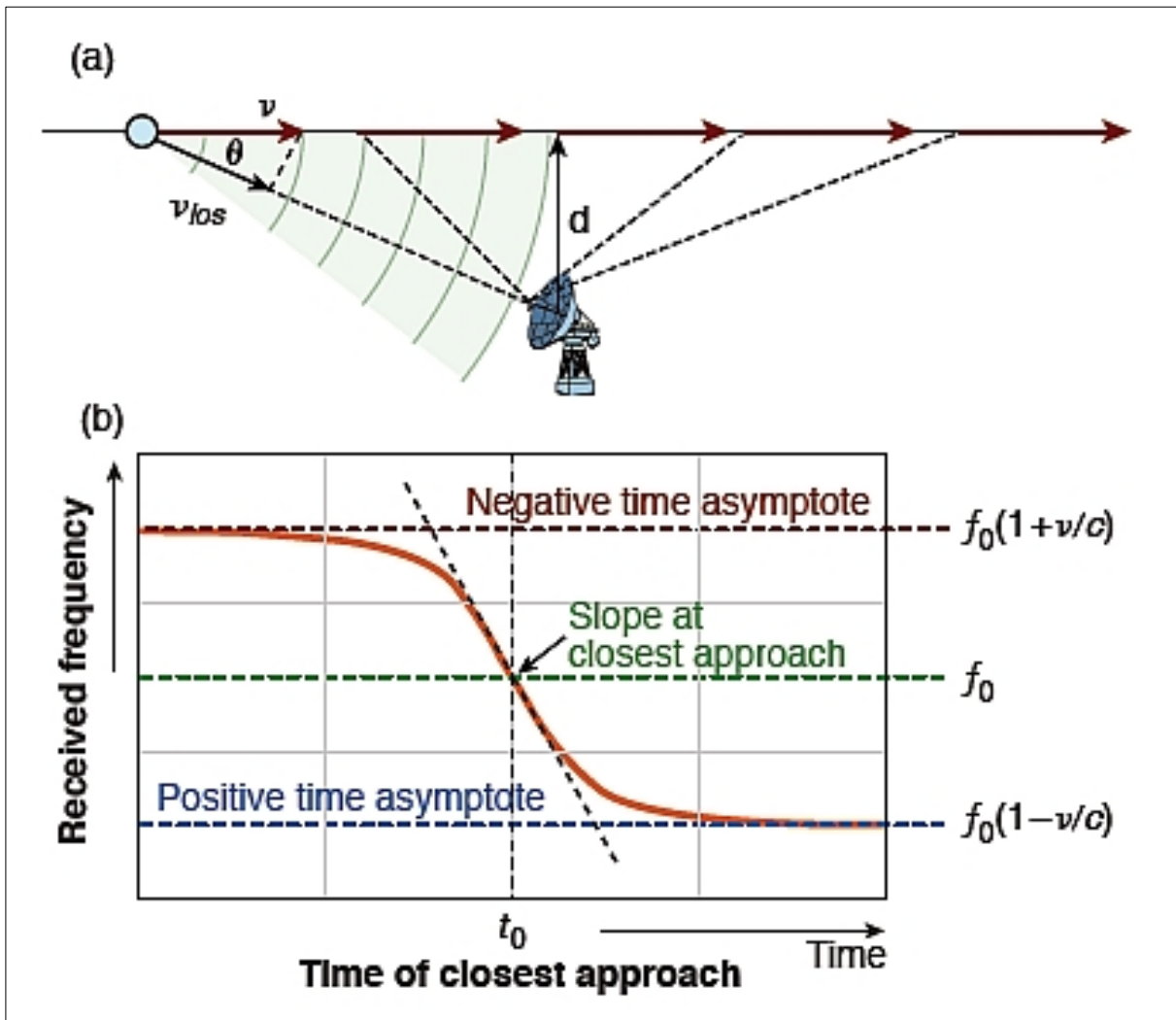


Figure 1579: The Doppler effect on the received frequency from a transmitter in straight-line uniform motion allows determination of transmitter frequency and velocity and the time and distance of closest approach. (a) Transmitter/receiver geometry and relative motion. (b) Received frequency pattern and principal measurements. ⁶⁸⁵⁹⁾

Doppler radar. A radar system which differentiates between fixed and moving targets by detecting the change in frequency of the reflected wave caused by the Doppler effect. The system can also measure target velocity with high accuracy.

Doppler shift. Displacement of spectral lines (or difference in frequency) in the radiation received from a source due to its relative motion in the line of sight. Sources approaching (–) the observer are shifted toward the blue; those receding (+), toward the red. Used to determine radial distance.

Delay Doppler radar altimeter. ⁶⁸⁶⁰⁾ An evolving technique which exploits signal processing algorithms borrowed from SAR processing schemes. When applied to an ocean-observing altimeter, real-time onboard processing achieves an integration level of the received signal that is about a magnitude higher (tenfold) than that achieved in conventional radar altimeters. This in turn translates into a tenfold reduction in required radiative power

6859) Robert L. Henderson, William S. Devereux, Thomas Thompson, "Navigation at APL: A Historical Perspective and a Look Forward," Johns Hopkins Technical Digest, Vol. 29, No 3, 2010, pp. 201–217, URL: <http://www.jhuapl.edu/techdigest/TD/td2903/Henderson.pdf>

6860) G. H. Fountain, Robert E. Gold, et al., "A Technology Path to Distributed Remote Sensing," Small Satellites for Earth Observation, 2nd International Symposium of IAA, Berlin, April 12–16, 1999, pp.189–193

of the transmitter (or into a smaller radar antenna or a combination of both effects), improving instrument performance considerably.

Downlink. Refers to the communication direction from a satellite (or aircraft) to a ground station. The prime information in this link is usually referred to as ‘telemetry.’ There may be different logical links in a downlink for instrument data and for the return (verification) of the telecommand data. In very elaborate communication systems with intermediate geostationary transmission satellites, the term ‘downlink’ is usually replaced by ‘return link’ to avoid confusion.

Drag–free control (DFC) system. ⁶⁸⁶¹⁾ A DFC system consists of accelerometers, thrusters and a computer. The DFC system is used to stabilize a satellite that is continually being perturbed by external disturbances by counteracting these disturbances so that they do not induce motion into the system that would otherwise interfere with the scientific measurements. A DFC accelerometer is implemented by enclosing a proof (test) mass in a housing within the spacecraft so that the proof mass is isolated from the surrounding environment. The motion of the proof mass is therefore not disturbed by external surface forces such as atmospheric drag or solar radiation pressure, but is only determined by gravity. A spacecraft with an onboard DFC is equipped with thrusters, specifically designed to allow it to maintain its position relative to the proof mass so that they do not come into contact with each other. Therefore, the spacecraft and the proof mass both behave as if they were not acted upon by external forces; this state is described as being drag–free.

Dryline. A meteorological term referring to a boundary which separates moist and dry air masses. The dryline is an important factor in the frequency of severe weather in the Great Plains of the continental USA. It typically lies north–south across the central and southern high Plains states during the spring and early summer, separating moist air from the Gulf of Mexico and dry desert air from the southwestern states.

Dual spin. Refers to a spacecraft design whereby the main body of the satellite is spun to provide attitude stabilization. In this concept the antenna assembly is despun by means of a motor and bearing system in order to continually direct the antenna earthward. The dual–spin configuration thus serves to create a spin–stabilized satellite.

Duty cycle. Fraction of orbital period in which a sensor (or a sensor mode) is actually operational, determined by the overall power limitations of the payload. The concept of a duty cycle applies in particular to sensors with large power requirements such as active sensors, in particular SAR instruments.

Dwell time. The short period of time during which a detector collects radiation from a target area or volume. – A very short dwell time usually results in a low (i.e. poor) signal–to–noise (SNR) ratio with all its problems of proper signal recognition and discrimination. A small dwell time also implies ‘fast’ detectors and electronics.

Dynamic range. Refers to the range of brightness levels that can be captured by a sensor (detector) without under– or oversaturation. The dynamic range of a sensor system is determined by the ratio of the maximum observable energy (Q_{\max}) and the minimum still–useful energy (noise level Q_{\min}); it is defined in decibels (dB) as $10 \log (Q_{\max}/Q_{\min})$. All radiant energy $< Q_{\min}$ vanishes into noise, while the energy above Q_{\max} disappears into the saturation of the detector (see also **Signal–to–Noise–Ratio**).

Earth: Earth is our home, and the third planet from the Sun. With a mean radius of 6371 km and a mass of 5.97×10^{24} kg, it is the fifth largest and fifth most–massive planet in the Solar System. And with a mean density of 5.514 g/cm^3 , it is the densest planet in the Solar System. Like Mercury, Venus and Mars, Earth is a terrestrial planet. But unlike these other planets,

⁶⁸⁶¹⁾ R. Leach, K. L. Neal, “Discussion of Micro–Newton Thruster Requirements for a Drag–Free Control System,” Proceedings of AIAA/USU Conference on Small Satellites, Logan, UT, Aug. 12–15, 2002, SSC02–VIII–1

Earth's core is differentiated between a solid inner core and liquid outer core. The outer core also spins in the opposite direction as the planet, which is believed to create a dynamo effect that gives Earth its protective magnetosphere.⁶⁸⁶²⁾

Combined with an atmosphere that is neither too thin nor too thick, Earth is the only planet in the Solar System known to support life. In terms of its orbit, Earth has a very minor eccentricity (approx. 0.0167) and ranges in its distance from the Sun between 147,095,000 km (0.983 AU) at perihelion to 151,930,000 km (1.015 AU) at aphelion. This works out to an average distance (aka. semi-major axis) of 149,598,261 km, which is the basis of a single Astronomical Unit (AU). The Earth has an orbital period of 365.25 days, which is the equivalent of 1.000017 Julian years. This means that every four years (in what is known as a Leap Year), the Earth calendar must include an extra day. Though a single solar day on Earth is considered to be 24 hours long, our planet takes precisely 23 h 56 m and 4 s to complete a single sidereal rotation (0.997 Earth days). Earth's axis is also tilted 23.439281° away from the perpendicular of its orbital plane, which is responsible for producing seasonal variations on the planet's surface with a period of one tropical year (365.24 solar days).

In addition to producing variations in terms of temperature, this also results in variations in the amount of sunlight a hemisphere receives during the course of a year. Earth has only a single moon: the Moon. Thanks to examinations of Moon rocks that were brought back to Earth by the Apollo missions, the predominant theory states that the Moon was created roughly 4.5 billion years ago from a collision between Earth and a Mars-sized object (known as Theia). This collision created a massive cloud of debris that began circling our planet, which eventually coalesced to form the Moon we see today.

What makes Earth special, you know, aside from the fact that it is our home and where we originated? It is the only planet in the Solar System where liquid, flowing water exists in abundance on its surface, has a viable atmosphere, and a protective magnetosphere. In other words, it is the only planet (or Solar body) that we know of where life can exist on the surface. In addition, no planet in the Solar System has been studied as well as Earth, whether it be from the surface or from space. Thousands of spacecraft have been launched to study the planet, measuring its atmosphere, land masses, vegetation, water, and human impact. Our understanding of what makes our planet unique in our Solar System has helped in the search for Earth-like planets in other systems.

Earth observation: The term Earth observation is generally used when referring to satellite-based remote sensing, which provides a whole range of information regarding the Earth's land masses, the oceans, the atmosphere and, in general, the environment and situational awareness, based on imagery or measurements.

Electromagnetic spectrum (EMS). The total range of wavelengths or frequencies of electromagnetic radiation, extending from the longest radio waves to the shortest known gamma rays. – EMS energy for passive remote sensing, as derived from the sun, is either **reflected sunlight** or **re-emitted thermal radiation**. The transfer mode of reflected radiation is dominant in the window associated with VNIR and SWIR, while the preferred mode of long-wave transfer (thermal radiation) is in the TIR window (see also Figure 1602 on page 123).

- In the VNIR and SWIR (0.4 – 3 μm) wavelength regions, the predominant mode of energy detection is that of reflected sunlight
- In the MWIR region (3–6 μm) the detected energy is a mixture of solar reflected and thermally emitted radiation
- In the TIR window (6–13 μm), practically all energy received (detected) is attributed to thermal emission.

6862) "3 new stories for 2016/08/18, What are the Planets of the Solar System?," Universe Today, Aug. 18, 2016, URL: <https://navigator.gmx.net/mail?sid=96efbf1bc40b61d63775c6de fcd8e9f0f0e2dfd31690b97068ae4a98f4cce0a8001d8589b12432582c540ebe7bb77a>

Note: Although the sun, with a brightness temperature of about 6000 K, is much hotter than the Earth's surface at about 290 K, the dominance of the Earth's thermal energy at longer wavelengths is a result of geometry (the sun subtends only about 0.5° at the Earth – the sun's disk angle is actually about $32'$), and that the solar energy is subsequently scattered by the Earth's surface into 2π space. – The solar energy, arriving at the top of the atmosphere, amounts to about $1.3\text{--}1.4\text{ kW/m}^2$.

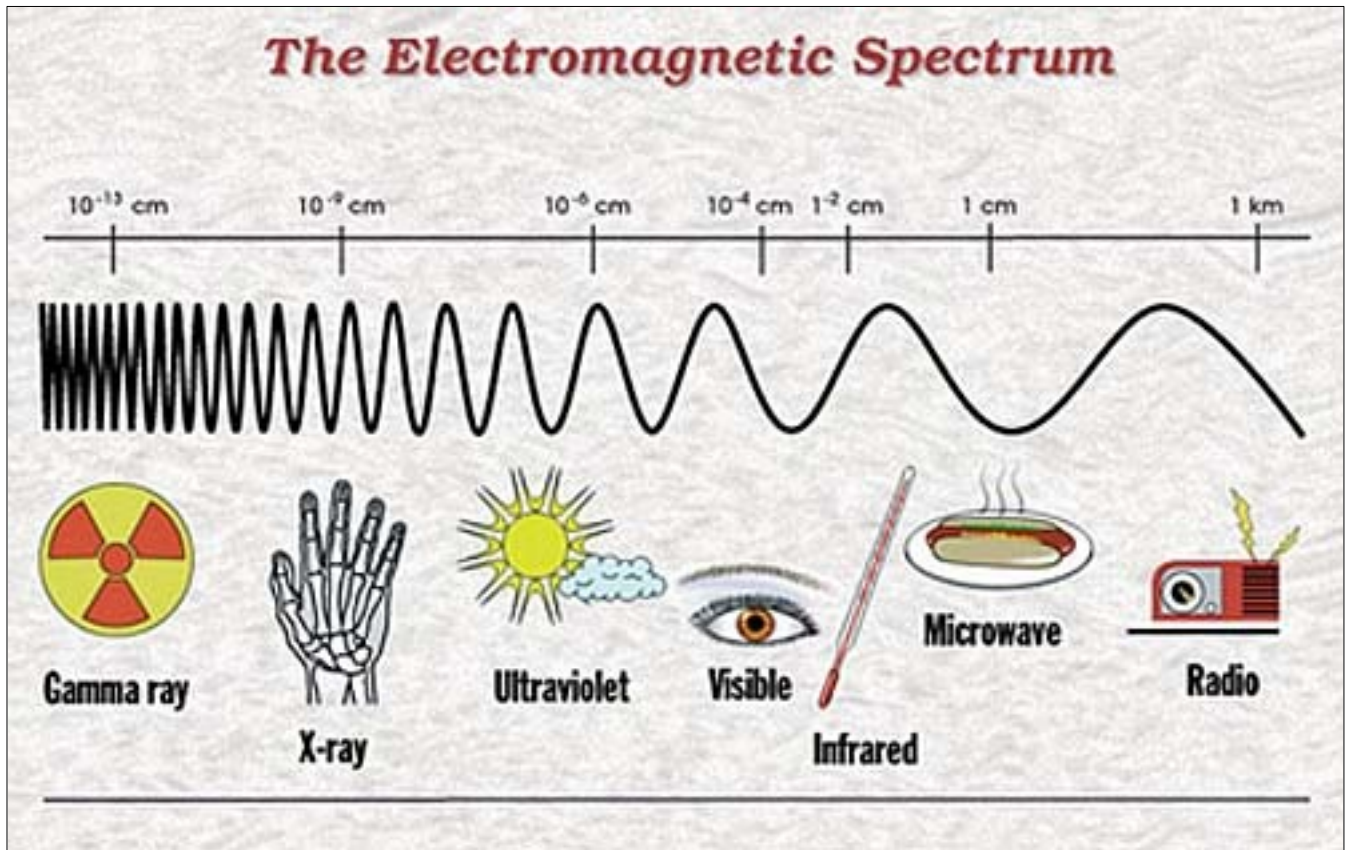


Figure 1580: Illustration of the EMS (image credit: NASA)

Electron tube. The term is the generic name for a class of devices that includes: vacuum tubes, phototubes, gas-filled tubes, cathode-ray tubes, and photoelectric tubes. An electron tube typically consists of two or more electrodes enclosed in a glass or metal-ceramic envelope, which is wholly or partially evacuated. Its operation depends on the generation and transfer of electrons through the vacuum from one electrode to the other. Electron tubes have properties that cannot be surpassed by solid-state devices for particular applications. Their thermal ruggedness, operating efficiency, and high-power capabilities are features well beyond those of solid-state devices. As components of electronic systems, electron tubes are used as amplifiers, rectifiers, signal generators, and switches (in particular in the microwave region).

Electron volt (eV). A unit of energy used in atomic and nuclear physics; the kinetic energy acquired by one electron in passing through a potential difference of 1 volt in vacuum. $1\text{ eV} = 1.602 \times 10^{-12}\text{ erg}$ (or $= 1.602 \times 10^{-19}\text{ Joule}$). An electron with an energy of 1 eV has a velocity of about 580 km/s. The wavelength associated with 1 eV is 12,398 Å. The eV is a convenient energy unit when dealing with the motions of electrons and ions in electric fields; the unit is also the one used to describe the energy of X-rays and gamma-rays. Nuclei in cosmic rays typically have energies ranging from about 1 MeV (or less) to many GeV

per nucleon. ⁶⁸⁶³⁾

Electrooptics. An imaging technique which uses optics, such as the collimation of light beams and the magnification of images by lenses and mirrors, rectification by prisms, and diffraction by gratings (usage: generally in the VNIR spectrum). – The newer devices of electrooptics make use of more electronic components such as the generation of light by lasers and solid state devices, featuring electronic scanning of the images and data presentation on electrically activated displays. To an increasing extent, computers are employing electrooptical techniques for their own operation and display. See also chapter Q.9.2.

Emissivity (ϵ). The ratio of radiative energy (power) emitted by a body to that emitted by a blackbody at the same temperature. For all cases: $\epsilon(\lambda) \leq 1$.

Energetic particles. These are electrons, ions, or atoms that have much higher energies than expected for the temperature of the gas in which they are transported (the solar wind is such a transport medium).

Energetic Neutral Atom (ENA). ENAs are created in the inner magnetosphere when charge exchange collisions occur between energetic ions and the cold neutral population of the Earth's extended atmosphere. ENAs travel in approximately straight-line trajectories away from the charge-exchange sites (because gravitational forces are negligible for typical energies of interest and they are unaffected by the Earth's electric and magnetic fields) and carry with them valuable information about the pitch angle and energy distributions of the ion population from which they were emitted. As of the 1990s the ENA emissions can actually be sensed remotely by appropriate imagers. Several NASA missions have such instrumentation: POLAR, IMAGE, and TWINS.

ENSO (El Niño Southern Oscillation). ENSO is regarded as a large-scale interannual climate variability (anomaly) especially with regard to precipitation regimes and sea surface temperature (SST) changes in the tropical Pacific Ocean. The warming effect of ENSO can dramatically alter precipitation patterns over much of the Pacific basin. Its recurrence every three to seven years provides a clear signal of climate variability on a global scale. Its land surface manifestations are illustrated by heavy torrential rains on the west coast of South America and droughts in Sahelian Africa, southern Africa, Australia, and eastern Brazil. The forecasting of ENSO events can greatly benefit the peoples and economies of the impacted areas.

Scientists believe **El Niño** conditions between Australia and South America are sparked when the steady westward trade winds weaken and even reverse direction. This wind shift moves a large mass of warm water, normally situated near Australia, eastward along the equator, pushing it toward the coast of South America. The transportation of such a large body of warm water affects evaporation, causing rain clouds to form that, in turn, alter typical atmospheric jet stream patterns around the world.

Background: In the 16 century, the El Niño climatic phenomenon was first observed by Peruvian fisherman as a warm current running along the coast of Peru. Since this recurrent event happened around the Christmas season, they christened the warm current as El Niño (meaning Christmas in Spanish). This virtually periodic phenomenon appears at two- to seven-year intervals, it has economic and environmental consequences that are sometimes catastrophic. The entire climate is thoroughly disturbed. Due to the warming of the Peruvian waters, normally the most productive in the world, the ocean is depleted of nutrients, causing rarefaction of the phytoplankton. A consequence of the disappearance of the aquatic life is a massive destruction of oceanic bird life.

Eötvös experiment. An experiment performed in 1909 by the Hungarian physicist Loránd Baron von Eötvös (1848–1919) to establish that the gravitational acceleration of a body

⁶⁸⁶³⁾ The energy unit Joule is named in honor of James Prescott Joule (1818–1889), a British physicist who established that the various forms of energy – mechanical, electrical, and heat – are basically the same and can be changed into one another. Thus he formed the basis of the law of conservation of energy, the first law of thermodynamics.

does not depend on its composition – i.e. that inertial mass and gravitational mass are exactly equal (later a major principle of Albert Einstein’s general theory of relativity). In Einstein’s version, the principle asserts that in free–fall the effect of gravity is totally abolished in all possible experiments and general relativity reduces to special relativity, as in the inertial state. Today, the linear gradient of gravity is defined in units of Eötvös, where 1 Eötvös = 10^{-9} s^{-2} ; i.e. difference of 10^{-9} ms^{-2} acceleration per meter. The vertical gradient of gravity at the Earth’s surface is about 3100 Eötvös.

Ephemeris. A tabular statement of the spatial coordinates of a celestial body or a spacecraft as a function of time.

Equatorial electrojet current. Current created around the Earth’s equator by counter–rotating electrons and protons. This electrojet current causes ionization, and subsequently UV radiation, similar to auroral phenomenon usually associated with the Earth’s F–Layer.

Equinox. Either of two points on the celestial sphere where the celestial equator intersects the ecliptic. At these two instances the sun is exactly above the equator and day and night are of equal length (see also **vernal equinox**).

Equivalence Principle (EP). A fundamental law of physics that states that gravitational and inertial forces are of a similar nature and often indistinguishable. EP in fact states that two fundamentally different quantities, inertia and passive gravitational mass, always be exactly proportional to one another. This is usually interpreted as implying that the two quantities are equivalent measures for a single physical property, the quantity of **mass** of an object; hence, the term “Equivalence Principle”.

A direct consequence of this Equivalence Principle is the ‘universality of free fall’ such that all objects fall with exactly the same acceleration in the same gravity field. EP turned out to be a major principle of Albert Einstein’s general theory of relativity.

The EP concept was formulated by Albert Einstein in 1907 and in 1911. He made the observation that the acceleration of bodies towards the center of the Earth with acceleration 1g is equivalent to the acceleration of inertially moving bodies that one would observe if one was on a rocket in free space being accelerated at a rate of 1g. Einstein deduced that free–fall is actually inertial motion (the universality of free–fall is also referred to as the **weak equivalence principle**). – By contrast, in Newtonian mechanics, gravity is assumed to be a force. (6864) (6865)

The **strong equivalence principle** of Einstein states that all of the laws of physics (not just the laws of gravity) are the same in all small regions of space, regardless of their relative motion or acceleration. This is the only form of the equivalence principle that applies to self–gravitating objects (such as stars), which have substantial internal gravitational interactions.

In the Newtonian form, EP implies that, within a windowless laboratory freely falling in a uniform gravitational field, experimenters would be unaware that the laboratory is in a state of nonuniform motion. All dynamical experiments yield the same results as obtained in an inertial state of uniform motion unaffected by gravity.

In physics, the symbol η (eta) is normally used to define the Eötvös ratio of two masses A and B in a gravitational field (in the absence of drag). By definition, η quantifies any differential acceleration that the two masses may experience as a fraction of their common–mode acceleration. If the EP holds true, then η is identically equal to zero.

The origins of the equivalence principle begin with Galileo demonstrating in the late 16th century that all objects are accelerated towards the center of the Earth at the same rate. Galileo measured the EP parameter η to approximately 1% level (or $\eta = 10^{-2}$).

(6864) “Equivalence principle,” Wikipedia, March 1, 2006, http://en.wikipedia.org/wiki/Equivalence_principle#History

(6865) N. A. Lockerbie, T. J. Sumner, “High Precision Tests of the Equivalence Principle,” Proceedings of the 39th ESLAB Symposium ‘Trends in Space Science and Cosmic Vision 2020,’ Noordwijk, The Netherlands, April 19–21, 2005, ESA SP–588

In the meantime the knowledge of the η value has improved steadily using better experimental techniques.

Some history and tests of the weak EP:

Historically, there have been distinct methods of testing the Equivalence Principle with macroscopic bodies. The most accurate tests have been the Eötvös torsion–balance experiments and the lunar–laser–ranging method.

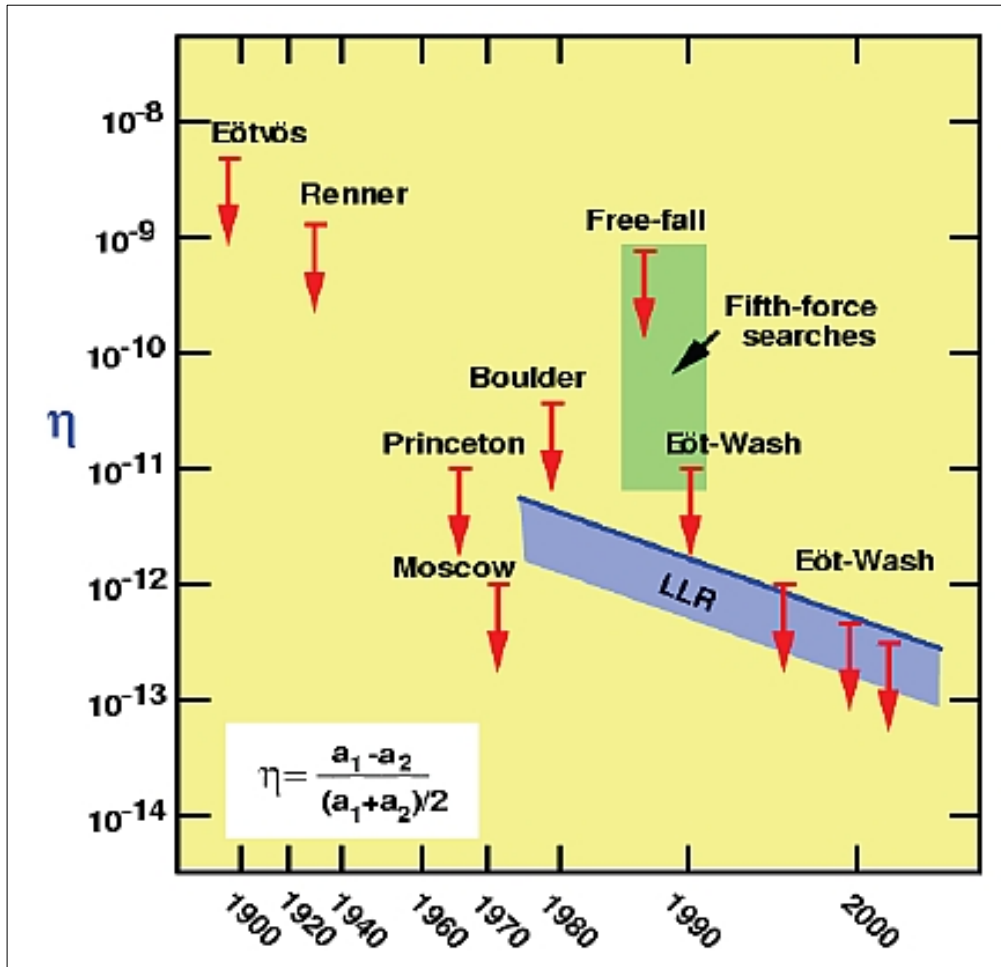


Figure 1581: Accuracy achieved in testing the EP (image credit: Clifford M. Will, University of Washington, St Louis, MO) ⁶⁸⁶⁶ ⁶⁸⁶⁷)

Legend to Figure 1581: Selected tests of the weak equivalence principle as a function of η , which measures fractional difference in acceleration of different materials or bodies. The free–fall and Eöt–Wash experiments were originally performed to search for a fifth force (green region, representing many experiments). The blue band shows evolving bounds on for gravitating bodies from lunar laser ranging (LLR).

- Experiments with ordinary pendulums test the principle of equivalence to no better than about one part in 10^5 . The Hungarian physicist Roland Eötvös (1909) measured the torsion on a wire, suspending a balance beam, between two nearly identical masses under the acceleration of gravity and the rotation of the Earth. Eötvös obtained sensitivity values in the range of $\eta = 10^{-9}$.

⁶⁸⁶⁶) Clifford M. Will, “The Confrontation between General Relativity and Experiment,” 2006, URL: <http://relativity.livingreviews.org/Articles/lrr-2006-3/>

⁶⁸⁶⁷) Naceur Gaaloul, T. v. Zoest, H. Ahlers, Y. Singh, S. T. Seidel, W. Herr, W. Ertmer, E. Rasel, M. Eckart, E. Kajari, S. Arnold, G. Nandi, R. Walser, W. P. Schleich, A. Vogel, K. Sengstock, K. Bongs, W. Lewoczko–Adamczyk, M. Schiemangk, A. Peters, T. Könemann, H. Müntinga, C. Lämmerzahl, H. Dittus, T. Steinmetz, T. W. Hänsch, J. Reichel, “Quantum tests of the Equivalence Principle with Atom Interferometry,” Proceedings of the 60th IAC (International Astronautical Congress), Daejeon, Korea, Oct. 12–16, 2009, IAC–09.A2.1.6

- In the 1960s a series of careful observations (employing up-to-date methods of servo control and observation) were conducted by the American physicist Robert H. Dicke and his colleagues (Princeton University). They found that the weak equivalence principle held to about one part in 10^{11} for the attraction of the sun on gold and aluminum (or EP sensitivity $\eta = 10^{-11}$).
- A later experiment (1971), with very different experimental arrangements, by the Russian researcher Vladimir Braginski, gave a limit of about one part in 10^{12} for platinum and aluminum (or $\eta = 10^{-12}$).
- In 1987 a group of physicists at the University of Washington, St. Louis, MO, referred to as the “Eöt–Wash” group, developed a number of very sensitive torsion bars for EP measurements. They achieved the most sensitive terrestrial measurements of EP so far with $\eta = \sim 5 \times 10^{-13}$.
- The Microscope mission of CNES (launch planned for 2012) employs FEEP thrusters for drag compensation. The objective is to achieve an EP sensitivity of $\eta = 10^{-15}$.
- A future NASA/ESA mission, called STEP (Satellite Test of the Equivalence Principle) or MiniSTEP (the launch date is not fixed), has the objective to test EP to a precision of 1 part in 10^{18} (or an EP sensitivity of $\eta = 10^{-18}$).

Equivalent (or effective) Isotropic Radiated Power (EIRP). A measure of power radiated by an antenna in the direction of a receiver, expressed as the equivalent power that would have to be radiated uniformly in all directions.

Erlang. A measure of communication (telephone) traffic load expressed in units of hundred call seconds per hour (CCS). One Erlang is defined as the traffic load sufficient to keep one trunk busy on the average and is equivalent to 36 CCS. The measure is also used for DCS (Data Collection Satellite) access capabilities.

Etalon. (see Fig 1582) A spectroscopic instrument measuring wavelengths by interference effects produced by multiple reflections between parallel half-silvered glass or quartz plates. A Fabry–Perot etalon is a non-absorbing, multi-reflecting device, similar in design to the Fabry–Perot interferometer, that serves as a multilayer, narrow-bandpass filter. The Fabry–Perot design contains plane surfaces that are all partially reflecting so that multiple rays of light are responsible for the creation of the observed interference patterns. The remarkable diversity of applications for etalons results from their high-resolution, high-performance imaging characteristics. A multiple etalon system design can provide an imaging interferometer that works in four distinct modes: as a spectro-polarimeter, a filter-vector magnetograph, an intermediate-band imager, and broadband high-resolution imager.

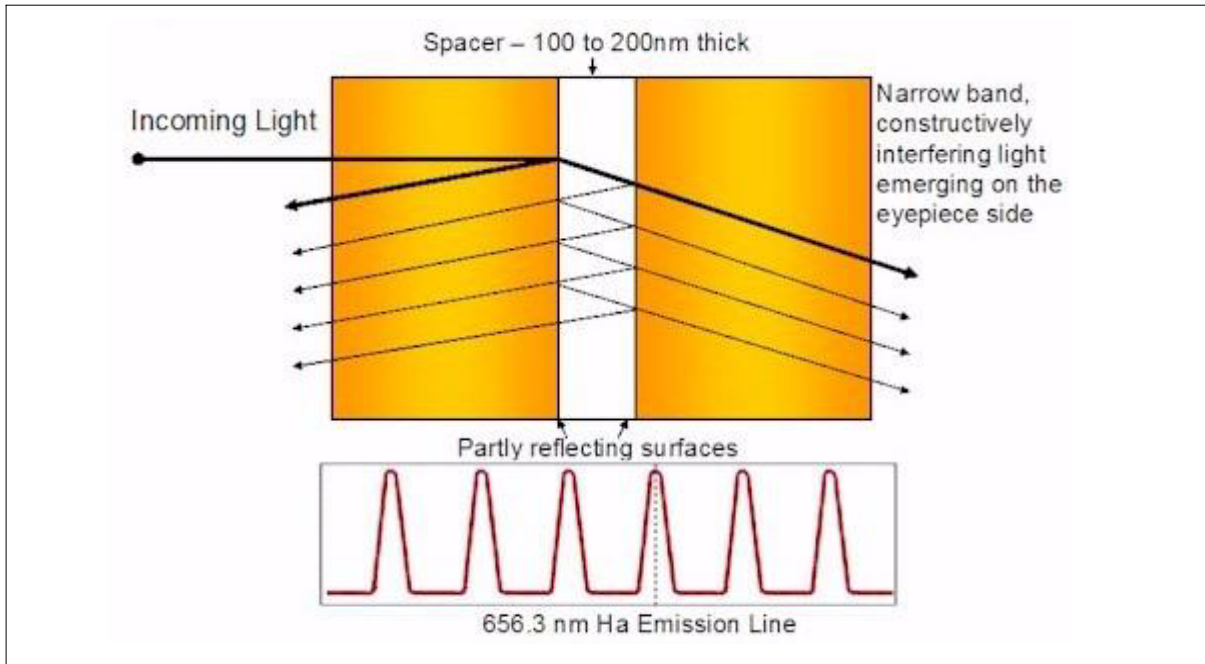


Figure 1582: Parallel plate scheme of a Fabry–Perot etalon

Étendue (also: etendue, see Fig. 1583). The term (French for ‘extent’) describes a very fundamental property of an optical system, namely $A \Omega$, the product of the area A of a light beam and the solid angle Ω contained within a beam. The importance of étendue lies in the fact that it is one of the major factors in determining the SNR (Signal–to–Noise Ratio) of a system; it is in fact a design parameter which can be maximized by the proper choice of configuration. Étendue has the units: $\text{cm}^2 \text{sr}$. It is a property that is at best conserved through an optical train, i.e., the system étendue will be that of lowest value in any part of the system. (6868)

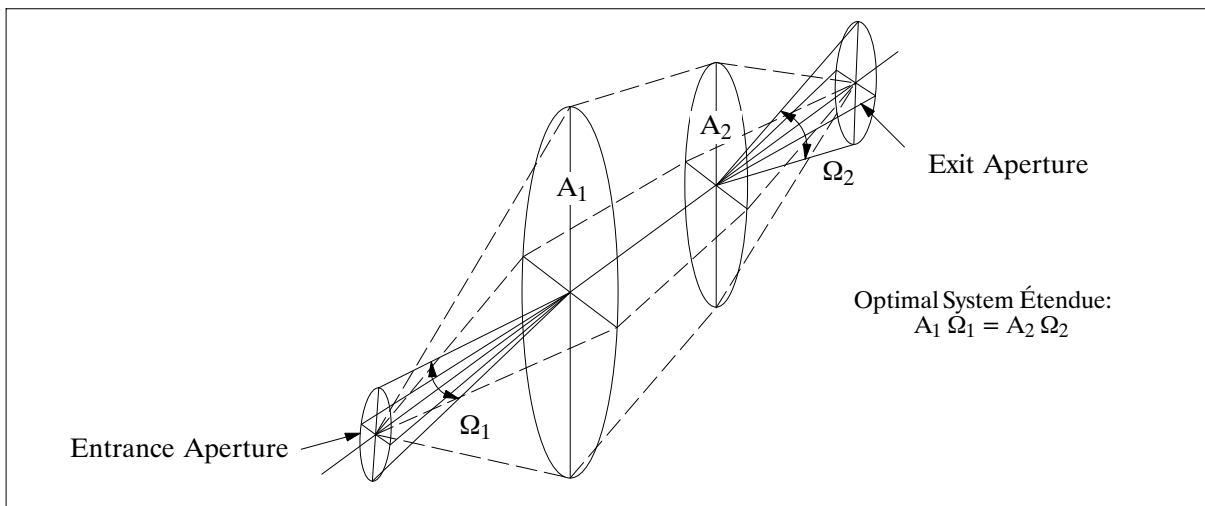


Figure 1583: Definition of étendue

Excimer. In photochemistry a molecular aggregate formed by loose association of an excited state and a ground state of the same compound, where such association does not occur between two ground state molecules.

Exoplanets. Refers to planets of other stars – outside of our own solar system (the existence of other living worlds like our own in the universe has been the subject of speculation for

centuries). Conventional telescopes are not powerful enough to discern extra-solar planets. The first widely accepted detection of extrasolar planets was made by Alexander Wolszczan (astronomer at the Pennsylvania State University) and Frail in 1992 (they discovered Earth-mass objects orbiting a pulsar). Earth-mass and even smaller planets orbiting a pulsar were detected by measuring the periodic variation in the pulse arrival time (they used a technique known as gravitational microlensing). The gravitational microlensing planet search technique differs from other planet search techniques in that it is most sensitive to planets at a separation of 1–5 AU from their star. Gravitational microlensing occurs when one star happens to cross in front of another as seen from Earth. The nearer star magnifies the light from the more distant star like a lens. If planets are orbiting the lens star, they boost the magnification briefly as they pass by.

– Most of the detection methods⁶⁸⁶⁹⁾⁶⁸⁷⁰⁾ currently used aim at measuring the reflex motion of the star around which a planet is possibly orbiting. Among those techniques, velocimetry (accurate spectroscopic Doppler measurements) and interferometry (differential astronomy) are limited to the detection of massive planets of about Jupiter’s mass. The first of these methods has been extremely successful since it led to the detection of several planets, including the first planet (in 1995) around a solar-type star by Michel Mayor and Didier Queloz of the Geneva Observatory, Sauverny, Switzerland.

– Astronomers estimate that the Milky Way contains up to 400 billion stars and thanks to the Kepler mission of NASA, the best estimate in 2014 is that every star in our galaxy has on average 1.6 planets in orbit around it. The Kepler Space Telescope has opened up a whole new universe and a new way of looking at stars as potential homes for other planets. Only about 20 years ago, we didn’t know if there were any other planets around any other stars besides our own. But now we know we live in a galaxy that contains more planets than stars.⁶⁸⁷¹⁾

Extinction. The superimposed effect of two radiation effects that cancel each other, e.g. absorption and scattering.

Fault-tolerant system. Refers to a system (model) where a fault is accommodated with or without performance degradation; but where a single fault does not develop into a failure on a subsystem or the system level.

False color. A color imaging process which produces an image that does not correspond to the true color of the scene (as seen by the eye).

Fast Fourier Transform (FFT). An algorithm that is often used to implement Discrete Fourier Transforms.

Feedback mechanisms. A sequence of interactions in which the final interaction influences the original one. Negative feedback: An interaction that reduces or dampens the response of the system in which it is incorporated. Positive feedback: An interaction that increases or amplifies the response of the system in which it is incorporated.

Field of Regard (FOR). The pointing capability of a sensor with regard to the cross-track direction and/or along-track direction may provide additional coverage to the sensor in its orbit. This can be an advantage for monitoring (or imaging) events that are outside the swath width [or FOV(Field of View)] of a regularly nadir-pointing instrument. – An imaging sensor with a cross-track and an along-track pointing capability may have the potential of stereo imaging by taking the same image from different along-track positions in the same orbit.

6869) A. Wolszczan, “Confirmation of Earth-Mass Planets Orbiting the Millisecond Pulsar PSR B1257+12,” *Science*, Vol. 264, Apr. 22, 1994, pp. 538–542

6870) M. Mayor, D. Queloz, “A Jupiter-mass companion to a solar-type star,” *Nature*, Vol. 378, Nov. 23, 1995, pp. 355–359

6871) Nancy Atkinson, “Kepler’s Universe: More Planets in Our Galaxy Than Stars,” *Universe Today*, Feb. 19, 2014, URL: <http://www.universetoday.com/109551/keplers-universe-more-planets-in-our-galaxy-than-stars/>

Field of View (FOV). The total range of viewing of a sensor into the direction of the target. The cross-track component of FOV is equivalent to the swath width (see also IFOV).

Fill Factor. Refers to the measurement of FPA (Focal Plane Array) performance, which measures how much of the total FPA is sensitive to IR energy. Because the FPA is made of numerous individual detector cells, the total amount of sensitivity is measured by the pathways used to separate the cells and transmit signals. The higher the fill factor, the higher the ratio of sensitivity.

Filter (in optical sensors). A device that – by interference absorption or reflection – selectively modifies the radiation transmitted through an optical system (see also ‘convolution filter’).

Fluorescence. Refers to the absorption of a photon of one wavelength and re-emission of one or more photons at longer wavelengths (known as Stoke’s shift), especially the transformation of ultraviolet radiation into visible light. Plants re-emit a portion of the absorbed radiant energy in the visible region into the red and near-infrared region (0.65–0.75 μm). The distribution of wavelength-dependent emission intensity caused by a given wavelength excitation is known as the emission spectrum. The method of fluorescence has its advantages over other spectroscopic methods mainly due to its high sensitivity (applications in cell biology, photochemistry and the environmental sciences). – Note, since lasers are used as the excitation light source to induced fluorescence, this active remote-sensing method has become known as the laser-induced fluorescence (LIF) technique.

Focal length (f). Distance measured along the optical axis from the image to the plane, where the axial imaging cone of light intersects the input light bundle. The F-number or F-stop is defined as f/d (the focal length divided by the diameter of the lens opening). In antenna design the term focal length refers to the distance from the center feed to the center of the dish.

Focal plane array (FPA). The term FPA refers to an assemblage of individual detector picture elements (“pixels”) located at the focal plane of an imaging system. Although the definition could include one-dimensional (“linear”) arrays as well as two-dimensional (2D) arrays, it is frequently applied to the latter. Usually, the optics part of an optoelectronic imaging device is limited only to focusing of the image onto the detector array. These so-called “staring arrays” are scanned electronically usually using circuits integrated with the arrays. The architecture of detector-readout assemblies has assumed a number of forms. The types of ROICs (Read-Out Integrated Circuits) include the function of pixel deselection, antiblooming on each pixel, subframe imaging, output preamplifiers, and may include yet other functions. Infrared imaging systems, which use 2D arrays, belong to so-called “second generation” systems. ⁶⁸⁷²⁾

2D FPA detectors, from UV to TIR, are used to create an image. (Earlier systems used either a single element detector or a small array of detectors and scanned the scene across the detectors with rotating mirrors). Most modern infrared commercial infrared cameras utilize an uncooled FPA as its infrared detector. Other FPA technologies include both uncooled (microbolometer, pyroelectric vidicon) and cooled (platinum silicide, indium antimonide) FPA systems.

Footprint. Refers to the projection of the instantaneous area of coverage of a sensor (or antenna) onto the Earth’s surface. A footprint may also be the instantaneous area of visibility of a data collection platform on a satellite.

⁶⁸⁷²⁾ A. Rogalski, “Optical detectors for focal plane arrays,” *Optoelectronics Review*, Vol. 12, No 2, 2004, pp. 221–245, URL: [http://www.wat.edu.pl/review/optor/12\(2\)221.pdf](http://www.wat.edu.pl/review/optor/12(2)221.pdf)

Formation flying definition: ⁶⁸⁷³⁾ Formation flying is defined as a set of more than one spacecraft whose dynamic states are coupled through a common control law. In particular, at least one member of the set must:

- 1) Track a desired state relative to another member, and
- 2) The tracking control law must at the minimum depend upon the state of this other member.

The second point is critical. For example, even though relative positions are being actively maintained, GPS is a constellation since orbit corrections only require an individual satellite's position and velocity (state).

Forward error correction (FEC). A transmission scheme which adds unique codes to the digital signal at the source so errors can be detected and corrected at the receiver.

Fourier Transform Spectrometer (FTS). An optoelectronic (or an optomechanical) instrument, usually for the infrared region of the spectrum, providing high spectroscopic resolution and sensitivity for remote-sensing applications (Earth surface imaging, atmospheric soundings, etc.). The technique employs the Fourier series concept as a means of converting a detector signal output – referred to as the interferogram – into a form useful for spectral analysis. There are several ways in which the detector signal can be created from the incident radiation. The approach taken by the majority of FTS instruments is to use an interferometer (Michelson, Sagnac, Fabry-Perot, etc.) and corresponding foreoptics (lenses) to create the interference pattern in such a way that each optical frequency is coded as a unique electrical signal output of the detector. The amplitude of each frequency is proportional to the incident radiation (see also chapter Q.6).

Frequency Division Multiple Access (FDMA). A process that shares a spectrum of frequencies among many users by assigning to each a subset of frequencies in which to transmit signals. Each user is assigned a unique center frequency within the operational bandwidth.

Fuel cells. Refer to devices that generate electricity cleanly and efficiently using hydrogen or hydrocarbons as the fuel. Fuel cells are more efficient in converting energy to electricity (work) than internal combustion engines and most combustion systems. Because of the more favorable environmental impact and more efficient energy conversion, fuel cells are viewed by many as the energy source of the 21st century. Fuel cells consist of an electrolyte – an ion containing liquid or solid – in contact with positive and negative electrodes. The device converts consumable fuels directly to electrical energy via chemical reactions. Fuel cells bypass the traditional route wherein a fuel is combusted to give work and heat, and the work from combustion powers a turbine that generates an electrical current. ⁶⁸⁷⁴⁾

The difference between a fuel cell and a battery is a battery contains the fuel to make electricity and can only be replenished by recharging whereas a fuel cell is a device that converts incoming fuel directly to electricity. At the start of the 21st century, fuel cells are being considered as potential energy sources for spacecraft. Current fuel cell systems are very heavy and it takes a fair amount of propulsion fuel to place one into space.

Full Width Half Maximum (FWHM). In the microwave region the resolution is often stated in terms of 'half-power points' or 'half-power response width' of the measuring system. The half-power width of a response is easier to describe than true resolution because the concept does not involve the contrast of the target. – The true resolution for targets of any character can be derived from the actual response and estimated from the half-power width (resolution) of microwave instruments.

⁶⁸⁷³⁾ D. P. Scharf, F. Y. Hadaegh, B. H. Kang, "A Survey of Spacecraft Formation Guidance," Proceedings International Symposium Formation Flying, Oct. 29–31, 2002, Toulouse, France

⁶⁸⁷⁴⁾ Note: A fuel and an oxidant are injected into a fuel cell and a chemical reaction occurs, generating electricity. This will continue until the fuel is consumed. If the products of the reaction can be transformed by electrolysis to the original fuels (e.g., hydrogen and oxygen from water), then the system is said to be reversible. In a secondary battery, it can be done in the same system – in a primary system another cell is needed to perform the electrolysis.

Fundamental physics in space: defined by the Committee on Space Research (COSPAR). It covers research activities which may be classified into two closely correlated categories, 1) the study of fundamental laws governing matter, space and time, and 2) the use of Space to investigate the principles governing the structure and complexity of matter.

Gain. A measure of the amplification of the input signal in an amplifier. The gain of an amplifier is often measured in decibels (dB), which is ten times the common logarithm of the ratio of the output power of the amplifier to the input drive power [= $10 \log (Q_2/Q_1)$].

Galaxy: A galaxy is a gravitationally bound system of stars, stellar remnants, interstellar gas, dust, and dark matter. The word galaxy is derived from the Greek word "galaxias", literally "milky", a reference to the Milky Way. Galaxies range in size from dwarfs with just a few billion (10^9) stars to giants with one hundred trillion (10^{14}) stars, each orbiting its galaxy's center of mass. Galaxies are categorized according to their visual morphology as elliptical, spiral and irregular. Many galaxies are thought to have black holes at their active centers. The Milky Way's central black hole, known as Sagittarius A, has a mass four million times greater than the Sun.

Galilei (Gal or gal). A unit of acceleration, 1 gal = 1 cm/s^2 ; 1 milligal = 10^{-3} cm/s^2 . The term is commonly used in gradiometry.

Gamma-ray bursts (GRBs). Gamma-ray bursts are the most energetic and luminous explosions known in the universe since the Big Bang. They are flashes of gamma rays, coming from seemingly random places in the sky and at random times, that last from milliseconds to many minutes, and are often followed by "afterglow" emission at longer wavelengths, releasing more energy in a few seconds than our sun will put out in its lifetime. GRBs were discovered in the 1960s by the US military Vela nuclear test detection satellites. ^{6875) 6876) 6877)}

Initially, the observations GRBs couldn't be properly identified. But in 1972, scientists of LANL (Los Alamos National Laboratory) were able to analyze various GRBs of the Vela spacecraft. They concluded that gamma-ray bursts were indeed "of cosmic origin."

- On April 5, 1991, NASA launched the CGRO (Compton Gamma Ray Observatory) which carried also BATSE (Burst And Transient Source Experiment) device. BATSE detected over 2,700 gamma-ray bursts in nine years. BATSE data proves that GRBs are uniformly distributed across the sky, not concentrated along the plane of the Milky Way. This means that gamma-ray bursts originate far outside of the Milky Way galaxy.
- In the early 21st century, astronomers are finally starting to unravel the cataclysmic events that cause these energetic explosions. Two classes of GRBs are recognized, long duration events and short duration events. Short gamma-ray bursts are likely due to merging neutron stars and not associated with supernovae. Long-duration GRBs are critical in understanding the physics of GRB explosions, the impact of GRBs on their surroundings, as well as the implications of GRBs on early star formation and the history and fate of the Universe.
- On April 23, 2009, the Swift satellite of NASA (launch Nov. 20, 2004) detected the most violent and distant GRB of a massive star so far in the early universe. This spectacular gamma ray burst was seen 13 billion light years away, with a redshift of 8.2, the highest ever measured. This event is referred to as GRB 090423. ⁶⁸⁷⁸⁾

6875) "Gamma-ray bursts – a brief history," URL: http://imagine.gsfc.nasa.gov/docs/science/known_11/GRB_history.pdf

6876) http://en.wikipedia.org/wiki/Gamma_ray_bursts

6877) http://imagine.gsfc.nasa.gov/docs/science/known_11/bursts.html

6878) Nancy Atkinson, "GRB Smashes Record for Most Distant Known Object," April 28, 2009, URL: <http://www.universetoday.com/2009/04/28/grb-smashes-record-for-most-distant-known-object/>

- On Dec. 09, 2011, the X–ray telescope of the Swift satellite observed GRB 111209A . The blast produced high–energy emission for an astonishing seven hours, earning a record as the longest–duration GRB ever observed. ⁶⁸⁷⁹⁾
- On April 27, 2013, Fermi’s GBM (Gamma–ray Burst Monitor) of NASA triggered on an eruption of high–energy light in the constellation Leo. The explosion is designated as **GRB 130427A**. Fermi’s LAT (Large Area Telescope) recorded one gamma ray with an energy of at least 94 GeV, or some 35 billion times the energy of visible light, and about three times greater than the LAT’s previous record. The GeV emission from the burst lasted for hours, and it remained detectable by the LAT for the better part of a day, setting a new record for the longest gamma–ray emission from a GRB. ⁶⁸⁸⁰⁾
- April 30, 2014: Research from an international team of scientists led by the University of Leicester has discovered for the first time that one of the most powerful events in our universe – GRBs – behave differently than previously thought.

GBRs are most probably powered by collimated relativistic outflows (jets) from accreting black holes at cosmological distances. Bright afterglows are produced when the outflow collides with the ambient medium. Afterglow polarization directly probes the magnetic properties of the jet when measured minutes after the burst, and it probes the geometric properties of the jet and the ambient medium when measured hours to days after the burst. ⁶⁸⁸¹⁾

High values of optical polarization detected minutes after the burst of GRB 120308A indicate the presence of large–scale ordered magnetic fields originating from the central engine (the power source of the GRB). Theoretical models predict low degrees of linear polarization and no circular polarization at late times, when the energy in the original ejecta is quickly transferred to the ambient medium and propagates farther into the medium as a blast wave.

The team detected circularly polarized light in the afterglow of GRB 121024A, measured 0.15 days after the burst. It is shown that the circular polarization is intrinsic to the afterglow and unlikely to be produced by dust scattering or plasma propagation effects. A possible explanation is to invoke anisotropic (rather than the commonly assumed isotropic) electron pitch–angle distributions. The team suggests that new models are required to produce the complex microphysics of realistic shocks in relativistic jets.

Geocoding. Registration of images to the reference geometry of a map. In this process the imagery is corrected for all source–dependent errors and transformed to the desired map projection, and resampled to a standard pixel size. This is also called georeferencing (or rectification) of the acquired scanner data to a local coordinate system with given ellipsoid and datum). The accuracy of the rectification result is crucial for overlaying the data with existing data sets or maps and using them for evaluations like change detection, map updating, etc. In general, the geometry of the raw imagery is influenced by several factors: ⁶⁸⁸²⁾

- The imager’s interior orientation
- The imager’s exterior orientation (position and attitude) sensor and optics system
- The boresight misalignment angles between navigation

6879) Nancy Atkinson, “New Kind of Gamma Ray Burst is Ultra Long–Lasting,” Universe Today, April 16, 2013, URL: <http://www.universetoday.com/101486/new-kind-of-gamma-ray-burst-is-ultra-long-lasting/>

6880) Francis Reddy, “NASA’s Fermi, Swift See ‘Shockingly Bright’ Burst,” NASA, May 3, 2013, URL: <http://www.nasa.gov/topics/universe/features/shocking-burst.html>

6881) K. Wiersema, S. Covino, K. Toma, A. J. van der Horst, K. Varela, M. Min, J. Greiner, R. L. C. Starling, N. R. Tanvir, R. A. M. J. Wijers, S. Campana, P. A. Curran, Y. Fan, J. P. U. Fynbo, J. Gorosabel, A. Gomboc, D. Götz, J. Hjorth, Z. P. Jin, S. Kobayashi, C. Kouveliotou, C. Mundell, P. T. O’Brien, E. Pian, A. Rowlinson, et al., “Circular polarization in the optical afterglow of GRB 121024A,” *Nature*, 30 April 30, 2014, doi:10.1038/nature13237

6882) Rupert Müller, M. Lehner, Rainer Müller, P. Reinartz, M. Schroeder, B. Vollmer, “A Program for Direct Georeferencing of Airborne and Spaceborne Line Scanner Images,” Pecora 15/Land Satellite Information IV Conference, ISPRS Commission I Mid–term Symposium/FIEOS (Future Intelligent Earth Observing Satellites), Nov. 10–14, 2002, Denver, CO

- The topography of the Earth's surface

Proper georeferencing requires all these items to be known to sufficient accuracy.

Geodesic: Within General Relativity, gravity is not a force acting on material particles, but instead is identified with curvature in spacetime geometry. Particles, in the absence of forces, travel in the straightest possible way in curved spacetime: this path is called a **geodesic**. In the absence of gravity, spacetime is flat and geodesics are simply straight lines travelled at constant velocity. – All experiments aimed at directly measuring curvature caused by celestial bodies, like gravitational wave observatories, measurements of Post–Newtonian light deflection and time delays, and general relativistic dragging of reference frames, require particles in **geodesic motion**. In addition, all experiments aimed at probing the limits of General Relativity and the possibility of alternative theories of gravitation search for violations of geodesic motion.

A spacecraft follows a pure geodesic when it is shielded from all external forces, i.e., when it is a drag–free satellite. Example of drag–free satellites are:

- TRIAD (Transit–improved DISCOS) of the US Navy and built by JHU/APL (launched Sept. 2, 1972). First satellite compensated for drag and radiation pressure. The drag–free concept was realized with DISCOS (Disturbance Compensation Device).
- GP–B (Gravity Probe–B), a NASA fundamental gravitational physics mission, developed at Stanford University. Launch of GP–B on April 20, 2004.
- GOCE (Gravity field and steady–state Ocean Circulation Explorer), an ESA geodynamics and geodetic mission. Launch of GOCE on March 17, 2009 (operational in 2013).

Geodesy. The science of measuring the dynamic shape (and size) of the Earth (the geoid), including the Earth's gravity field and its rotation. This definition includes the orientation of the Earth in space, and temporal variations of the Earth's orientation, its surface and its gravity field. Space geodesy is an interdisciplinary science which uses spaceborne and airborne remotely sensed, and ground–based measurements to study the shape and size of the Earth, the planets and their satellites, and their changes; to precisely determine position and velocity of points or objects at the surface or orbiting the planet, within a realized terrestrial reference system. Geodetic techniques include VLBI observations, SLR and LLR measuring distances to satellites and other heavenly bodies (moon, etc.), GPS and other satellite microwave techniques making use of the Doppler effect of signals sent out by satellites. All these measurement techniques are used to define the celestial and terrestrial reference systems, and to measure the link between the two systems, namely the Earth rotation parameters, and the origin of the reference frame relative to the geocenter. – By virtue of their geometric properties, the geodetic measurement techniques make possible other precise measurements such as ocean radar altimetry, land/ice laser altimetry, GPS occultation measurements for atmospheric sounding, interferometric SAR, and network ground movements. The dynamic orbit of a spacecraft can be used to determine the Earth's gravity field, the technique is called SST (Satellite–to–Satellite Tracking).⁶⁸⁸³⁾

Geographical Information System (GIS). A combination of mutually referring data sets of various kinds of position–bound thematic data (database) and the necessary software to visualize this database, to manipulate it interactively and to analyze it in order to attain meaningful results.

Geoid. The Earth's conceptual gravitational equipotential surface (an ellipsoid) near the mean sea level, used as a datum for gravity surveys (a hypothetical ocean surface at rest – with the absence of winds, tides and currents). The geoid also serves as a reference surface for topographic heights, for example, as they are shown on maps. The geoid itself represents

⁶⁸⁸³⁾ B. F. Chao, "Geodesy Is Not Just for Static Measurements Any More," EOS Transaction of AGU, Vol. 84, No 16, April 22, 2003, pp. 145 and 150

the surface of zero height. A precise model of the geoid (a level surface defined by equal gravitational potential) as defined by the gravity field, is crucial to understanding more about ocean circulation.

Note: The notion of a geoid was already suggested by Carl Friedrich Gauss in 1828, he referred to it as the “geometric surface of the Earth.”

Earth’s gravity field varies due to uneven mass distribution and the dynamics of the surface and Earth’s interior. These include high mountains, deep ocean trenches, ground water reservoirs, oil, gas and mineral deposits, tidal effects, sea–level rise, Earth’s rotation, volcanic eruptions and changes in topography. A precise knowledge of the ‘geoid’ – a virtual surface with an equal gravitational potential – is needed for many applications, such as levelling and construction, and for understanding ocean currents and monitoring sea–level dynamics.

In Figure 1584, the Geoid is illustrated by ESA’s GOCE Earth Explorer, showing how Earth would look if its shape were distorted to make gravity the same everywhere on its surface. The colors in the image represent deviations in height (–100 m to +100 m) from an ideal geoid. The blue shades represent low values and the reds/yellows represent high values.

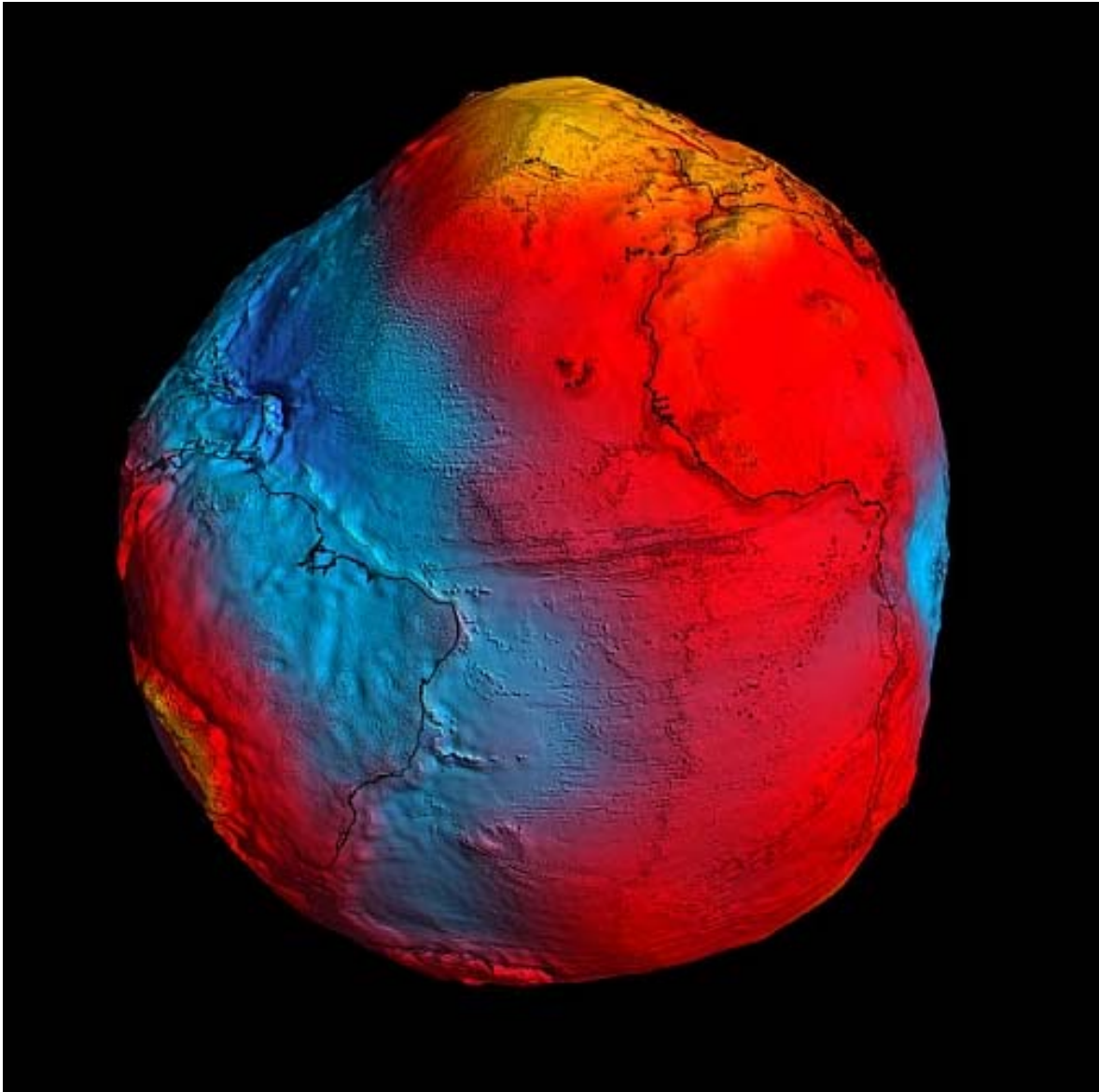


Figure 1584: The global model of the Earth’s gravity field – the Geoid (image credit: ESA, GFZ, DLR)

Geomorphology (from Greek ‘morph,’ form). The explanatory science dealing with the form (shape) and surface configuration of the solid Earth (land and submarine relief features).

Geospace. The term refers to the region of the Earth’s envelope that is affected by the sun, not only by its continuous radiation, but also by the solar wind with its associated phenomenon of space weather. The sun’s variability (referred to as solar activity) can trigger storms in geospace, so-called magnetic storms can disrupt modern navigation systems, communications networks and satellites systems in general. High-energy radiation of such solar activity may also affect life on Earth. Earth may be viewed as an island in our solar system under the protective shield of the magnetic field and the atmosphere. The study of geospace involves an understanding of the changing sun and its effects on the Earth system as a whole, including life. Geospace is commonly defined as the region of space, that stretches from the Earth’s upper atmosphere to the outermost reaches of the Earth’s magnetic field.

Geospatial information. ⁶⁸⁸⁴⁾ Defined as information that identifies the geographic location and characteristics of natural or constructed features and boundaries on the Earth, including: statistical data; information derived from, among other things, remote sensing, mapping and surveying techniques; and mapping, charting and geodetic data, including geodetic products.

Geosynchronous orbit. An orbit in which the satellite’s orbital period is identical to the orbital period of the Earth. A geosynchronous orbit, unlike a geostationary orbit (with zero inclination, where the satellite motion relative to the Earth is at rest), does not impose any restrictions on the orbit’s eccentricity or inclination.

GNSS (Global Navigation Satellite System): Refers to the radionavigation constellations in L-band such as GPS (USA), GLONASS (Russia), Galileo (Europe), Compass/Beidou (China), QZSS (Japan), and IRNSS (India).

GNSS-R (Global Navigation Satellite System-Reflectometry): Refers to reflected GNSS (signals) observables from the open ocean or land surface (to be measured by an airborne or spaceborne instrument). The GNSS-R signals in L-band may be used in a wide field of applications (altimetry, soil moisture, sea state monitoring, etc.).

The GNSS-R technique is being used in a bistatic radar configuration as sources of opportunity (a passive bistatic/multistatic remote sensing technique to obtain altimetric as well as other information, surface wind parameters). The underlying principle in GNSS-R is the use of reflected signals (a multipath method of reflected, refracted and scattered signals) to infer properties of the reflecting surfaces. The sea surface provides the ocean-atmosphere link, regulating momentum, energy and gas exchange, and several fundamental ocean circulation features are directly related to wind-wave induced turbulent transports in the oceanic mixed layer. In particular, eddies and gyres are fundamental agents for mixing, heat transport and feedback to general circulation, as well as transport of nutrients, chemicals and biota for biochemical processes.

Gradiometry. Study of the spatial gradient of the Earth’s gravitational field.

Graphene: The creation of graphene, a wonder material that promises to transform the future, is already the stuff of scientific legend. As a piece of brilliant serendipity, it stands alongside the accidental discovery of penicillin by Alexander Fleming – and it might prove just as valuable. ⁶⁸⁸⁵⁾

Two Russian-émigré scientists at the University of Manchester (UK), **Andrei Geim and Kostya Novoselov**, were playing about with flakes of carbon graphite in an attempt to inves-

⁶⁸⁸⁴⁾ J. C. King, “Keynote Address to the ASPRS 2000 DC Annual Conference,” PE&RS, Sept. 2000, pp. 1043–1053

⁶⁸⁸⁵⁾ Steve Connor, “The graphene story: how Andrei Geim and Kostya Novoselov hit on a scientific breakthrough that changed the world... by playing with sticky tape,” The Independent, March 18, 2013, URL: <http://tinyurl.com/bl-dr34o>

tigate its electrical properties when they decided to see if they could make thinner flakes with the help of sticky Scotch tape.

They used the tape to peel off a layer of graphite from its block and then repeatedly peeled off further layers from the original cleaved flake until they managed to get down to flakes that were only a few atoms thick. They soon realized that by repeatedly sticking and peeling back the Scotch tape they could get down to the thinnest of all possible layers, one atom thick – a material with unique and immensely interesting properties.

When the two scientists won their joint Nobel prize in physics in 2010 for their ground-breaking experiments, the Nobel committee made a point of citing the “playfulness” that was one of the hallmarks of the way they have worked together. — Prof. Andrei Geim (* 1958), is a Dutch national while Dr. Kostya Novoselov (* 1974), holds British and Russian citizenship. Both are natives of Russia and started their careers in physics there.

Graphene, a two-dimensional crystal of pure carbon, is a superlative material. It is the thinnest and strongest substance known to science – about 100 times stronger than steel by weight. A square meter of graphene, a thousand times thinner than paper, made into a hammock would be strong enough to cradle a 4 kg cat, but weigh no more than one of its whiskers. It is a good conductor of electricity, is stretchable and yet is almost transparent. It conducts heat better than any other known substance. It acts as a barrier to the smallest atom of gas – helium – and yet allows water vapor to pass through.

The inventive step that made Geim and Novoselov into Nobel laureates was to find a way of transferring the ultra-thin flakes of graphene from Scotch tape to a silicon wafer, the material of microprocessors. Once they did this the extraordinary electrical properties of graphene could be witnessed and explored, including its “ghostly” quantum state when electrons start to behave weirdly as if these particles have no mass. “The excitement would exist even without these unusual properties because graphene is the first two-dimensional material. It seems obvious now because we can suspend it in the air and do almost anything with it, but at the beginning, it was by no means obvious that it would be stable,” Novoselov says.

“And then on top of that, there are other excitements such as the very unusual electronic properties, that we’ve never come across before. Then, there are the unusual optical properties, chemical properties and many more.”

“We have a really unique opportunity here in that quite a few unusual properties are combined in one material; the strongest, the most flexible, the most stretchable, the most conductive, optically transparent and something which is a good gas barrier. So you can invent quite a few new applications that were not possible before,” he adds.

The potential uses for graphene appear almost limitless. They range from new types of flexible electronics that could be worn on clothes or folded up into a pocket, to a new generation of very small computers, hyper-efficient solar panels and super-fast mobile phones. Yet at the heart of graphene is a honeycomb structure of carbon atoms – described as “atomic chickenwire”. Carbon is the basic element of life, which means that graphene could be the focus of a new industrial revolution based on electronic components that are biodegradable and sustainable. If there was ever a building material for a new, green economy, graphene could be it. As a result, the Government has actively supported a new National Graphene Institute (NGI) in Manchester, which will be completed by 2015.

Graphene: Printing of RFID antennas with graphene ink

Researchers from the University of Manchester, together with BGT Materials Ltd., a graphene manufacturer in the United Kingdom, have successfully printed a radio frequency antenna using compressed graphene ink. The antenna performed well enough to make it practical for use in RFID (Radio Frequency Identification) tags and wireless sensors, the researchers said. Even better, the antenna is flexible, environmentally friendly, and could

be cheaply mass-produced. The study demonstrates that printable graphene is now ready for commercial use in low-cost radio frequency applications, said Zhirun Hu, a researcher in the School of Electrical and Electronic Engineering at the University of Manchester. (6886) (6887)

Since graphene was first isolated and tested in 2004, researchers have striven to make practical use of its amazing electrical and mechanical properties. One of the first commercial products manufactured from graphene was conductive ink, which can be used to print circuits and other electronic components.

Graphene ink is generally low cost and mechanically flexible, advantages it has over other types of conductive ink, such as solutions made from metal nanoparticles. To make the ink, graphene flakes are mixed with a solvent, and sometimes a binder like ethyl cellulose is added to help the ink stick. Graphene ink with binders usually conducts electricity better than binder-free ink, but only after the binder material, which is an insulator, is broken down in a high-heat process called annealing. Annealing, however, limits the surfaces onto which graphene ink can be printed because the high temperatures destroy materials like paper or plastic.

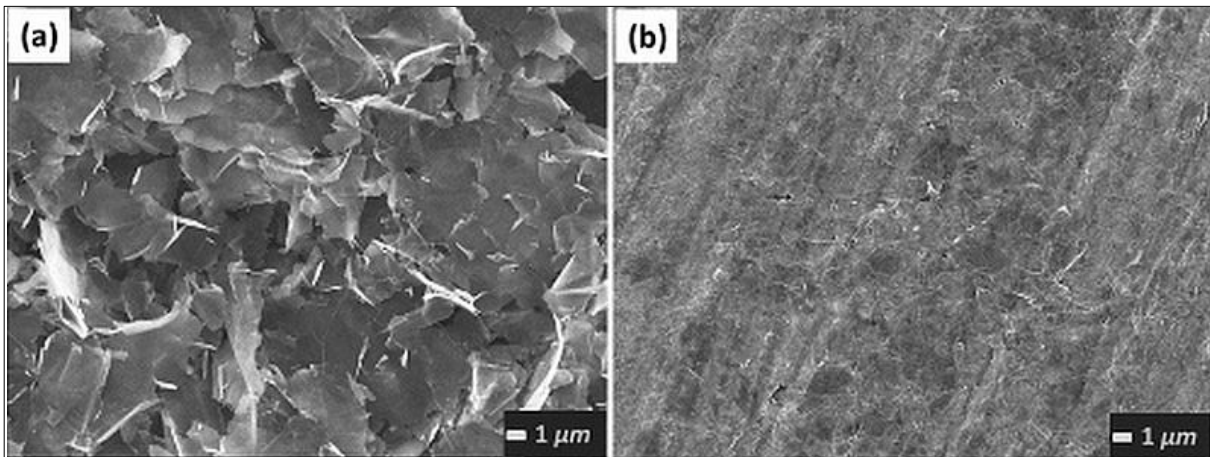


Figure 1585: These scanning electron microscope images show the graphene ink after it was deposited and dried (a) and after it was compressed (b). Compression makes the nanoflakes more dense, which improves the electrical conductivity of the laminate (image credit: University of Manchester)

The University of Manchester research team, together with BGT Materials Ltd., found a way to increase the conductivity of graphene ink without resorting to a binder. They accomplished this by first printing and drying the ink, and then compressing it with a roller, similar to the way new pavement is compressed with a road roller. Compressing the ink increased its conductivity by more than 50 times. The resulting "graphene laminate" was also almost two times more conductive than previous graphene ink made with a binder. The high conductivity of the compressed ink, which enabled efficient radio frequency radiation, was one of the most exciting aspects of the experiment, as reported by the research team.

The researchers tested their compressed graphene laminate by printing a graphene antenna onto a piece of paper. The antenna measured approximately 14 centimeters long, and 3.5 millimeter across and radiated radio frequency power effectively, said Xianjun Huang, who is a PhD candidate in the Microwave and Communications Group in the School of Electrical and Electronic Engineering.

Printing electronics onto cheap, flexible materials like paper and plastic could mean that wireless technology, like RFID tags that currently transmit identifying info on everything

6886) "Scientists Print Radio Frequency Antenna with Graphene Ink," *Aerospace & Defense Technology*, July 8, 2015, URL: <http://www.aerodefensetech.com/component/content/article/22494>

6887) Xianjun Huang, Ting Leng, Xiao Zhang, Jia Cing Chen, Kuo Hsin Chang, Andre K. Geim, Kostya S. Novoselov, Zhirun Hu, "Binder-free Highly Conductive Graphene Laminate for Low Cost Printed Radio Frequency Applications," *Applied Physics Letters*, Vol. 106, published online: May 19, 2015

from cattle to car parts, could become even more ubiquitous. Most commercial RFID tags are made from metals like aluminum and copper, Huang said, expensive materials with complicated fabrication processes that increase the cost.

Grating. See **diffraction grating**.

Gravity: Four fundamental forces govern all interactions within the Universe. They are weak nuclear forces, strong nuclear forces, electromagnetism, and **gravity**. Of these, gravity is perhaps the most mysterious. While it has been understood for some time how this law of physics operates on the macro-scale – governing our Solar System, galaxies, and super-clusters – how it interacts with the three other fundamental forces remains a mystery.

Naturally, human beings have had a basic understanding of this force since time immemorial. And when it comes to our modern understanding of gravity, credit is owed to one man who deciphered its properties and how it governs all things great and small – Sir Isaac Newton. Thanks to this 17th century English physicist and mathematician, our understanding of the Universe and the laws that govern it would forever be changed. While we are all familiar with the iconic image of a man sitting beneath an apple tree and having one fall on his head, Newton’s theories on gravity also represented a culmination of years worth of research, which in turn was based on centuries of accumulated knowledge. ⁶⁸⁸⁸⁾

Newton presented his theories in the “Principia” — *Philosophiae Naturalis Principia Mathematica* (“Mathematical Principles of Natural Philosophy”), which was first published in 1687. In this volume, Newton laid out what would come to be known as his Three Laws of Motion, which were derived from Johannes Kepler’s Laws of Planetary Motion and his own mathematical description of gravity. These laws would lay the foundation of classical mechanics, and would remain unchallenged for centuries – until the 20th century and the emergence of Einstein’s Theory of Relativity.

Since energy and mass are equivalent, all forms of energy, including light, also cause gravitation and are under the influence of it. This is consistent with Einstein’s General Theory of Relativity, which remains the best means of describing gravity’s behavior. According to this theory, gravity is not a force, but a consequence of the curvature of spacetime caused by the uneven distribution of mass/energy.

⁶⁸⁸⁸⁾ Matt Williams, “Who Discovered Gravity?,” *Universe Today*, April 28, 2016, URL: <http://www.universetoday.com/53898/who-discovered-gravity/>

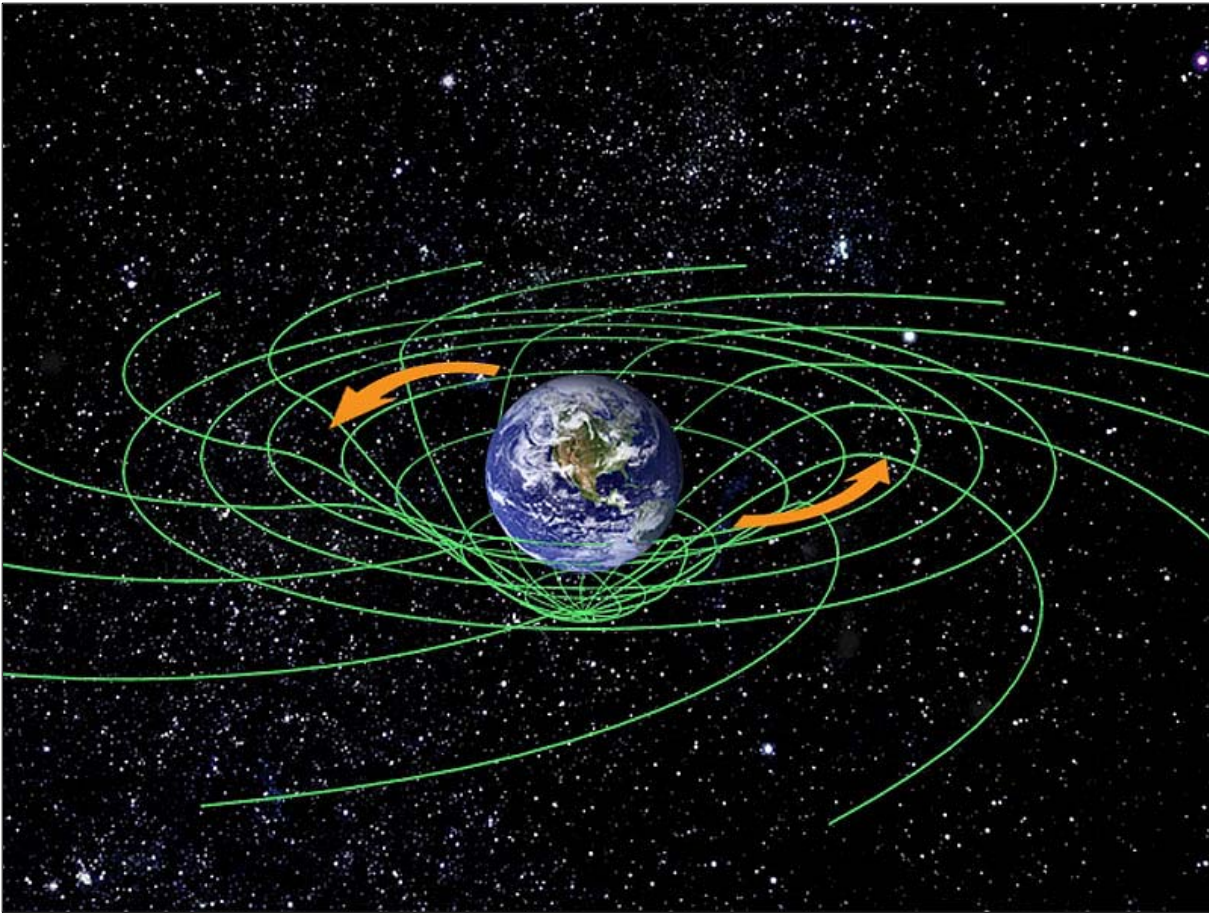


Figure 1586: Artist's rendition of the frame–dragging effect in which space and time are dragged around a massive body (image credit: Stanford University)

Earth's gravity: The force of Earth's gravity is the result of the planet's mass and density – 5.97237×10^{24} kg and 5.514 g/cm^3 , respectively. This results in Earth having a gravitational strength of 9.81 m/s^2 close to the surface (also known as 1 g), which naturally decreases the farther away one is from the surface.

Gravity assist maneuver. In orbital mechanics, a gravitational slingshot, gravity assist or swing–by is the use of the relative movement and gravity of a planet or other celestial body to alter the path and speed of a spacecraft, typically in order to save fuel, time, and expense. The gravity assist can be used to decelerate a spacecraft (useful when traveling to an inner planet) or accelerate a spacecraft (useful when traveling to an outer planet). Examples: 6889)

- The Mariner 10 probe of NASA was the first spacecraft to use the gravitational slingshot effect to reach another planet, passing by Venus on Feb. 5, 1974, on its way to becoming the first spacecraft to explore Mercury.
- The Galileo spacecraft was launched by NASA in 1989 aboard Space Shuttle Atlantis. Its original mission was designed to use a direct Hohmann transfer, but following the loss of the Space Shuttle Challenger, Galileo's intended Centaur booster rocket was no longer allowed to fly on Shuttles. Using a less–powerful solid booster rocket instead, Galileo flew by Venus once and Earth twice to reach Jupiter in December, 1995.
- In 1990, ESA and NASA launched the spacecraft Ulysses to study the polar regions of the Sun. All the planets orbit approximately in a plane aligned with the equator of the Sun (ecliptic plane). To move to an orbit passing over the poles of the Sun, the spacecraft would

6889) http://en.wikipedia.org/wiki/Gravity_assist

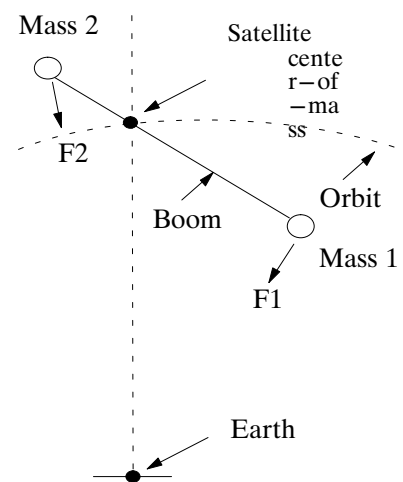
have to eliminate the 30 km/s speed it inherited from the Earth's orbit round the sun and gain the speed needed to orbit the sun in the pole-to-pole plane — tasks which were impossible with current spacecraft propulsion systems.

Ulysses was sent towards Jupiter, aimed to arrive at a point in space just "in front of" and "below" the planet. As it passed Jupiter, the probe 'fell' through the planet's gravity field, borrowing a minute amount of momentum from the planet; after it had passed Jupiter, the velocity change had bent the probe's trajectory up out of the plane of the planetary orbits, placing it in an orbit that passed almost over the poles of the Sun. This maneuver required only enough fuel to send Ulysses to a point near Jupiter, which is well within current technologies.

- The MUSES-C (Mu Space Engineering Satellite; launch May 9, 2003), a deep space asteroid sample return mission of JAXA, Japan (Note: MUSES-C is also referred to as **Hayabusa**) used an Earth swing-by one year after launch (the gravity assist maneuver took place May 19, 2004), spacecraft arrival at the target in Oct. 2005, two months of close target observations and sampling after landing.
- The Rosetta spacecraft of ESA (launch March 2, 2004) on its way to a rendezvous with Comet 67P/Churyumov-Gerasimenko in 2014, swung by the home planet (Earth) in March 2005, followed by the MESSENGER spacecraft of NASA in August of the same year.
- etc.

Many gravity-gradient stabilized LEO S/C use extendable booms to achieve a favorable moment-of-inertia distribution providing two-axis (pitch and roll) attitude control. The addition of an actuator, such as a momentum wheel, to a gravity-gradient stabilized S/C provides gyroscopic stiffness to passively stabilize the third (yaw) axis. The advantages of gravity-gradient stabilization are simplicity of control, long life and low power requirements.

Gravity-gradient boom. A deployable extension of a spacecraft (a rod fixed to the S/C with a small mass at its other end) intended to give the spacecraft elongated mass properties to contribute to gravity-gradient stability (the concept was first successfully demonstrated by JHU/APL on the Transit 5A-3 satellite with a launch on June 16, 1963). The principle: The attractive force F_1 of mass 1 (satellite) about the common center of mass exceeds the attractive force F_2 of mass 2. Hence, a torque arises to align the satellite to the vertical. — An elongated dumbbell-shaped spacecraft is the most gravity gradient stable configuration with the long axis oriented vertically in orbit, i.e. (usually) the smaller mass is always pointing toward the center of the Earth. The gravity-gradient torque, small even for LEO S/C, decreases with the cube of the orbital radius. In GEO, gravity-gradient stabilization can barely be achieved.



Gravity wave. A wave disturbance in which buoyancy acts as the restoring force on parcels displaced from hydrostatic equilibrium. In fluid dynamics, gravity waves are waves generated in a fluid medium or at the interface between two mediums (e.g. the atmosphere or ocean) which has the restoring force of gravity or buoyancy. When a fluid parcel is displaced on an interface or internally to a region with a different density, gravity restores the parcel toward equilibrium resulting in an oscillation about the equilibrium state or wave orbit. Gravity waves on an air-sea interface are called surface gravity waves or surface waves

while internal gravity waves are called internal waves. Ocean waves generated by wind are examples of gravity waves.

Gravity waves are global events. Much like the ripples on a massive pond, these large-scale waves can propagate from an atmospheric disturbance over thousands of kilometers. These waves are maintained by the gravitational force of Earth pulling down and the buoyancy of the atmosphere pushing up. In 2008, new research suggests that gravity waves passing over storms can spin up highly dangerous and damaging tornados.⁶⁸⁹⁰

Grazing angle. Angle between the instantaneously transmitted signal of an active sensor (a SAR) and the local horizontal of the target. In other words, the grazing angle = $90 - \theta$, where θ is the incidence angle. Grazing incidences occur usually at very shallow angles. It's like skipping stones across a stream (the rock will skip only if it glances off the surface at a small angle).

Greenhouse effect. Refers to the trapping of heat from the sun by the atmosphere (mainly by its water vapor, which absorbs and reemits infrared radiation), in the same manner that the sun's heat is trapped by the glass walls of a greenhouse. The atmosphere, like the glass, is largely transparent to the sun's radiation, but it absorbs the longer wavelength radiation from the Earth's surface into which the sun's radiation is converted.

Greenhouse gases. Those atmospheric trace gases, such as water vapor (H_2O), carbon dioxide (CO_2), methane CH_4), chlorine, and CFC's that are largely transparent to incoming solar radiation but opaque to outgoing longwave radiation. Their action is similar to that of glass in a greenhouse. Some of the longwave (infrared) radiation is absorbed and reemitted by the greenhouse gases. The effect is to warm the surface and the lower atmosphere of the Earth. Water vapor is the most important greenhouse gas due to its dominant role in the atmospheric processes (evaporation, cloud formation, etc.). CO_2 is the most prevalent known anthropogenic greenhouse gas. Its concentration has increased by more than 95 ppm in the last 150 years. The majority of CO_2 variability occurs in the lower atmosphere (~ 1000 to 800 mbar). The natural geographic distribution and temporal variability of CO_2 sources and sinks, however, are still not well understood.

Gridding. Use of a uniform system of rectilinear lines superimposed on imagery (such as photographs, mosaics, maps, charts, or other representations of the Earth's surface).

Ground pattern. Any specific identifying feature of the land surface which can be used for classification purposes.

Ground sampling distance (GSD). GSD is defined as the distance moved on the ground (in the along-track direction of the target area) during the integration period of the detector line array of an imaging instrument. Normally, the GSD is equated with the spatial resolution of a pixel or simply with IFOV (Instantaneous Field of View). However, this need not be the case. If the radiometric and electronic performance of a sensor allow, the GSD can be made smaller than IFOV to achieve better image quality because of the reduction of smear.

Ground track. Refers to the vertical projection of the actual flight path of a satellite (or aircraft) onto the surface of the Earth.

Ground truth. Reference data which is collected in the field (generally on or near the Earth's surface). The objective is to verify remotely-sensed primary sensor data against a typical 'reference.' Ground truth data is generally used in support of the analysis of remotely-sensed data. This ground truth may be gathered either by a single ground station, or by a network of ground stations (including buoys, remote terminals, etc.) whose data is collected by a 'data collection' satellite, or by airborne underflights of a spaceborne sensor. The

6890) I. O'Neill, "Gravity Waves in the Atmosphere can Energize Tornados (Video)," March 19, 2008, URL: <http://www.universetoday.com/2008/03/19/gravity-waves-in-the-atmosphere-can-energize-tornados-video/#more-13260>

ground reference that is being sought depends very much on the application. For instance, it may be a simple visual verification of the vegetation types in a particular scene, or it may be a particularly prepared ground patch with known radiative characteristics (reflectance, etc.) that is being used for the calibration of an airborne sensor. A very prominent ground truth station is for instance MOBY (see chapter R.145 on page 535), which makes in situ measurements of ocean color near the Hawaiian island of Lanai.

Hall effect. Edwin H. Hall (1855 – 1938, American physicist) discovered what became known as the Hall effect in 1879 when investigating the nature of force acting on a conductor carrying a current in a magnetic field. Today, Hall effect measurements are used to characterize the electronic transport properties of semiconductors and metals. – In a model Hall effect measurement system, a uniform current density flows through a uniform slab of electrically conducting material in the presence of an applied perpendicular magnetic field. The Lorentz force then acts on the moving charge carriers, deflecting them to one side of the sample to generate an electric field perpendicular to both the current density and the applied magnetic field. The ratio of the perpendicular electric field to the product of current density and magnetic field is the Hall coefficient. The ratio of the parallel electric field to the current density is the resistivity.

The Hall effect is also employed in Hall plasma thrusters (electric propulsion).

Heliosphere. The heliosphere is a region of space dominated by the Sun, a sort of bubble of charged particles in the space surrounding the Solar System, "blown" into the interstellar medium (the hydrogen and helium gas that permeates the galaxy) by the solar wind. The heliosphere extends at least 13 billion km beyond all the planets in our solar system. It is dominated by the sun's magnetic field and an ionized wind expanding outward from the sun. Outside the heliosphere, interstellar space is filled with matter from other stars and the magnetic field present in the nearby region of the Milky Way.

High-pass filter (in optical sensors). An absorption filter pervious to electromagnetic radiation above a certain wavelength only.

Hosted payloads: In general, a hosted payload is a sensor or instrument that is integrated to a host spacecraft and dependent upon one or more of the host spacecraft's subsystems for functionality.

In particular, the term 'hosted payload' refers to the utilization of available capacity on commercial satellites to accommodate additional transponders, instruments, or other spacebound items. A hosted payload is a third party subsystem/module integrated in a commercial satellite that operates independently of the main spacecraft but shares the satellite resources, including power, thermal and communications. ^{6891) 6892)}

By offering "piggyback rides" or "hitchhiking" opportunities on commercial spacecraft already scheduled for launch, satellite firms allow entities such as government agencies to send sensors and other equipment into space on a timely and cost-effective basis. The hosted payloads concept is similar to the ridesharing or multiple manifesting concept, but instead of sharing a space launch vehicle, the partners share a satellite bus. In some cases, hosted payloads may also be referred to as secondary payloads. Hosted payloads on commercial satellites in GEO provide in particular many launch opportunities.

A particularly promising area of development for hosted payloads is in Earth-observation missions. There are countless environmental monitoring missions, both heritage and new, which will need to be launched in the coming years. Whether observing the earth's oceans, its atmosphere, or worldwide weather patterns, government Earth-observation satellites

6891) <http://www.space.commerce.gov/general/commercialpurchase/hostedpayloads.shtml>

6892) Don Brown, "Hosted Payloads – New Roles for Commercial Satellite Operators in Government Space Missions," APSCC Quarterly Newsletter, April 2009, URL: http://www.intelsatgeneral.com/docs/news/2009-07-16_APSCC_Hosted_Payloads.pdf

have increasing requirements to incorporate a variety of payloads in affordable and timely programs. Individual sensors, flown as hosted payloads, represent an opportunity to off-load missions from increasingly challenged government satellite programs.

Humidity. The water vapor content of air. The term is commonly used to mean “relative humidity,” the dimensionless ratio of vapor that a given quantity of air can contain at a given temperature, expressed as a percentage. Perfectly dry air has a relative humidity of 0%; totally saturated air has a relative humidity of 100%.

Huygens’s principle (Christian Huygens, Dutch physicist, 1629–1695). A very general principle applying to all forms of wave propagation which states that every point on the instantaneous position of an advancing wave/phase front may be regarded as a source of secondary spherical ‘wavelets’. The position of the phase front an instant later is then determined as the envelope of all secondary wavelets. – This principle is extremely useful in understanding the effects due to refraction, reflection, diffraction, and scattering of all types of radiation. At his time, Huygens was the leading proponent of the wave theory of light.

Hydrologic cycle (or water cycle). Refers to a conceptual model of the hydrosphere that describes the storage and movement of water between the biosphere, atmosphere, and lithosphere. Its cycle describes the journey of water, as water molecules make their way from the Earth’s surface to the atmosphere, and back again. Virtually all the water of the hydrosphere is in constant circulation, moving through the hydrological cycle, a vast series of interchanges of geographic position as well as of physical state. Broadly speaking, the hydrologic cycle involves the transfer of water from the oceans through the atmosphere to the continents and back to the oceans. The processes involved are complex combinations of evaporation, transpiration, condensation, precipitation, runoff, infiltration, subterranean percolation, and others. The mean residence time of water in the atmosphere, on the land surface, and in the oceans is an important climate parameter.

The **hydrosphere** consists of all liquid and frozen surface waters (including the oceans, lakes and streams), groundwater held in soil and rock, and atmospheric water vapor. The Earth’s total water budget is estimated at roughly $1.386 \times 10^9 \text{ km}^3$. However, of this amount, 97.5% is contained in the oceans and other saline bodies of water. Of the remaining 2.5% of fresh water, 68.7% is tied up in glaciers (and permanent snow cover) and polar ice caps (1.72% of total budget). A total of 29.9% of the fresh water exists as ground water. Hence, only 0.3% of the total amount of the fresh waters on Earth are concentrated in lakes, reservoirs and river systems (renewable water). Hence, approximately 0.62% of the total amount of water may be regarded as ‘freshwater’ in rivers, lakes and groundwater supplies.

The following list provides estimates of the static water budgets in the hydrosphere, consisting of a total budget of $1.386 \times 10^9 \text{ km}^3$:

- Ocean volume (97.5%): $1.35 \times 10^9 \text{ km}^3$ (salt water)
- Fresh water volume (2.5% of total): $34,600,000 \text{ km}^3$
 - Polar ice caps + glaciers+ permanent snow (68.9%): $24,000,000 \text{ km}^3$
 - Ground water (29.9%): $10,300,000 \text{ km}^3$
 - Lakes and rivers systems(0.3%): $100,000 \text{ km}^3$ (renewable water)
 - Other (0.9%) including soil moisture, swamp water and permafrost: $300,000 \text{ km}^3$
- The average atmospheric water content (<0.01% of Earth’s total) is equivalent to an estimated volume of about $13,000 \text{ km}^3$.⁶⁸⁹³ This corresponds to a mass of 13×10^{12} tons. The atmosphere provides in effect a gigantic transport service [it would take 130 billion trucks (13×10^{10}), each with a net load of 100 tons, to transport this amount of water]. Most

6893) [http://ww2010.atmos.uiuc.edu/\(Gh\)/guides/mtr/hyd/home.xml](http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/hyd/home.xml)

water is transported in the form of water vapor, which is actually the third most abundant gas in the atmosphere. Precipitation is the primary mechanism for transporting water from the atmosphere to the surface of the Earth.

- If all the atmospheric water fell as precipitation at once, the Earth would be covered with only about 2.5 cm of water.
- Each day, about $1,170 \text{ km}^3$ of water evaporate or transpire into the atmosphere. ⁶⁸⁹⁴⁾

Water cycle (according to Ref. 6893): Every year, the turnover of water on Earth involves $577,000 \text{ km}^3$ of water. This is water that evaporates from the oceanic surface ($502,800 \text{ km}^3$) and from land ($74,200 \text{ km}^3$). The same amount of water falls as precipitation, $458,000 \text{ km}^3$ on the ocean and $119,000 \text{ km}^3$ on land. The difference between the precipitation and evaporation from the land surface ($119,000 - 74,200 = 44,800 \text{ km}^3/\text{year}$) represents the total runoff of the Earth's rivers ($42,700 \text{ km}^3/\text{year}$) and direct groundwater runoff to the ocean ($2,100 \text{ km}^3/\text{year}$). These are the principal sources of fresh water to support the necessities of life and the economic activities of humankind.

Water of Hydrosphere	Period of Renewal	Water of Hydrosphere	Period of Renewal
World ocean	2500 years	Ground water	1400 years
Polar ice	9700 years	Mountain glaciers	1600 years
Ground ice of permafrost zone	10000 years	Lakes	17 years
Soil moisture	1 year	Atmospheric moisture	8 days

Table 970: Periods of water resources renewal on the Earth

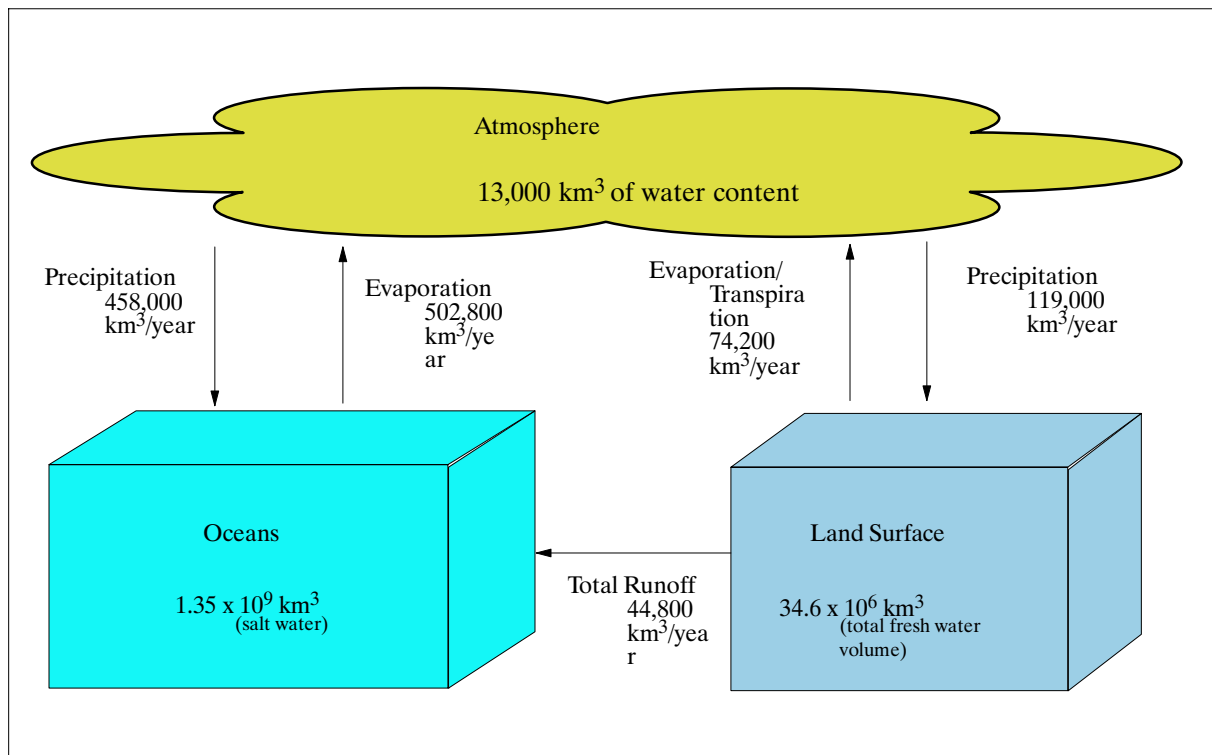


Figure 1587: Illustration of yearly water volumes in the hydropheric cycle

Hydrometeors. These are cloud scatterers (when measured by a lidar or radar instrument) in different phases such as rain or frozen precipitation with a definite fall velocity.

⁶⁸⁹⁴⁾ "How much water is there on, in, and above the Earth?," USGS, URL: <http://ga.water.usgs.gov/edu/earthhowmuch.html>

Hyperspectral imager (optical region). In remote sensing the term implies a spectral signature of narrow, continuous and contiguous spectral bands per pixel, i.e. a fine spectral resolution ($\Delta\lambda/\lambda = 1 - 5\%$), over an extended spectral range. A hyperspectral sensor has a minimum of 20 spectral bands (normally 30 – 200 bands). On the other hand, “multispectral” usually implies fewer, spectrally broader bands, which may be noncontiguously spaced color bands per pixel. Hyperspectral imaging implies a hyperspectral signature for each pixel of the image. The detailed spectral information captured in a hyperspectral image allows detailed examination of the observed scene.

CCDs (Charged Coupled Device) detectors have been used for many years for hyperspectral imaging missions and have been extremely successful. However, CMOS sensors have a number of advantages which means that they will probably be used for hyperspectral applications in the longer term. There are two main advantages with CMOS sensors: ⁶⁸⁹⁵⁾

- First a hyperspectral image consists of spectral lines with a large difference in intensity; in a frame transfer CCD the faint spectral lines have to be transferred through the part of the imager illuminated by intense lines. This can lead to cross-talk and whilst this problem can be reduced by the use of split frame transfer and faster line rates CMOS sensors do not require a frame transfer and hence inherently will not suffer from this problem.
- Second, with a CMOS sensor the intense spectral lines can be read multiple times within a frame to give a significant increase in dynamic range.

6895) P.A.Jerram, M.Fryer, J.Pratlong, A.Pike, A.Walker, B.Dierickx, B.Dupont, A.Defernez, “Hyperspectral CMOS Imager,” ICSO 2010 (International Conference on Space Optics), Rhodes Island, Greece, Oct. 4–8, 2010, URL: http://congrex.nl/ICSO/Papers/Session%201A/FCXNL-10A02-1986550-1-JERRAM_ICSO_PAPER.pdf

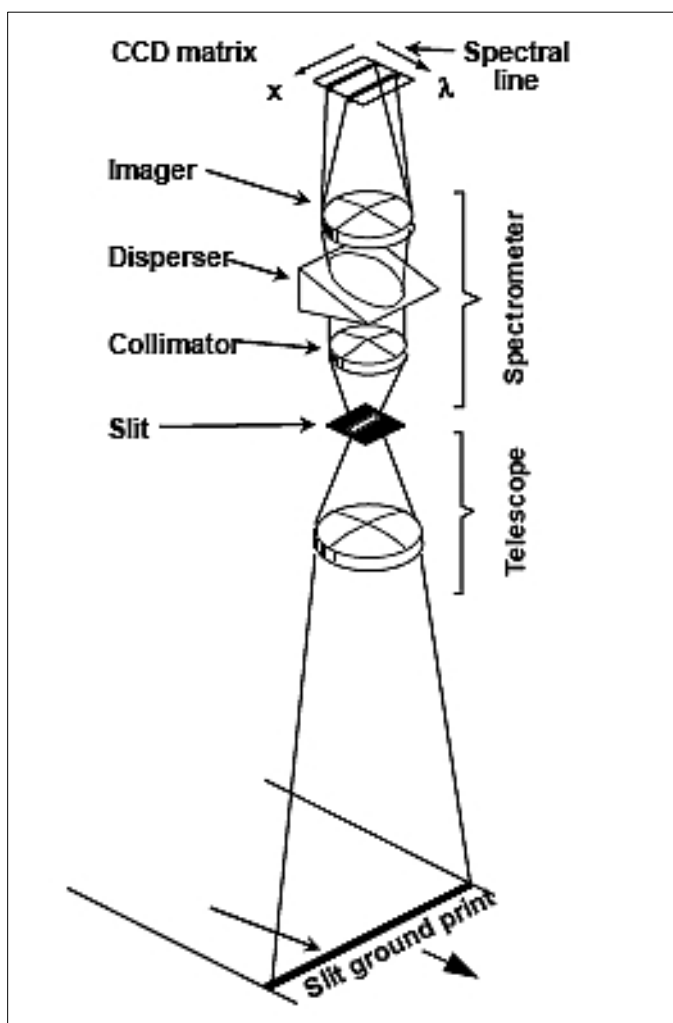


Figure 1588: Schematic view of a hyperspectral imager (Ref. 6895)

Hyperspectral microwave operations: In analogy to hyperspectral imaging in the optical (infrared) region, the term “hyperspectral microwave” is being used since about 2010 to refer generically to microwave sounding systems with approximately 50 spectral channels or more. The term “hyperspectral microwave” is used to indicate an equivalent all-weather sounding performance similar to that of hyperspectral infrared sounders in clear air with vertical resolution of approximately 1 km. Hyperspectral microwave operation is achieved through the use of independent RF antenna/receiver arrays that sample the same area/volume of the Earth’s surface/atmosphere at slightly different frequencies and therefore synthesize a set of dense, finely spaced vertical weighting functions.⁶⁸⁹⁶⁾

Hyperspectral infrared sensors have been available since the 1990s and have demonstrated high-resolution sounding performance. However, clouds substantially degrade the information content in the infrared portion of the spectrum, and a hyperspectral microwave sensor is therefore highly desirable to achieve all-weather performance.

Image. Remotely sensed imagery (collected by CCD instrument, camera, or radar – in a wide range of the electromagnetic spectrum) is measured data which is transformed by numerical algorithms into an image. This is referred to as “computed imaging.”⁶⁸⁹⁷⁾ An image is a two-dimensional grid of data; each of its elements is a pixel (picture element) whose coordinates are known and whose light intensity has a DN (Digital Number) value. The co-

6896) W. J. Blackwell, C. Galbraith, T. Hancock, R. Leslie, I. Osaretin, M. Shields, P. Racette, L. Hilliard, “Design and Analysis of a Hyperspectral Microwave Receiver Subsystem,” Proceedings of IGARSS (International Geoscience and Remote Sensing Symposium), Munich, Germany, July 22–27, 2012

6897) Other forms of computed imaging (i.e. a restructured image of measured data) are in such fields as: tomography, x-ray crystallography, electron microscopy, seismic imaging, and radio astronomy.

ordinates of the pixels and their DN values describe the image in terms of rows, called 'lines', and columns, called 'samples'. An 8-bit pixel provides up to 256 brightness levels (level 0 is set to black, while level 255 is set to white); the brightness levels are also referred to as 'grayscale levels.' In 'false color image processing', those pixels which have the same DN value are assigned an arbitrary color. This enhancement technique is used, for example, to differentiate between various types of terrain or species of vegetation – to reveal changes which are otherwise not perceptible to the human eye.

Image correction. The adjustment of an image for errors: geometric, radiometric, etc.

Image correlation. The ability to locate or match a region of an image with a corresponding region of another image which can be taken with a different sensor at a different viewing angle.

Image degradation. Loss of resolution due to modulation transfer function defects including motion blur, nonlinear amplitude response, shading and vignetting and channel noise.

Image enhancement. The improvement of images to facilitate better interpretation (false color processing is an example), or further digital processing to develop a specific theme or to highlight certain features in an image series.

Image motion compensation. Algorithms (hardware and/or software) counteracting image motion during integration time, thereby reducing image blur. The blur effect increases when relative velocities of the sensor platform are noticeable with respect to the image integration time. The sensor platform attitude parameters are also important inputs for motion compensation. For low-flying aircraft motion compensation is normally in the forward direction. There are also algorithms in use for antenna motion compensation. For instance, the short-term scanning motion of the antenna is measured by IMU (Inertial Measurement Unit). This data is used as input to compensate the pulse-to-pulse phase of the radar to maintain coherence during synthetic aperture.

Image quality. Refers to the apparent central core size of the observed image, often expressed as an angular image diameter that contains a given percentage of the available energy. Sometimes it is taken to be the full width at half maximum (FWHM) value of the intensity versus the angular radius function. A complete definition of image quality would include measurements of all image distortions present, not just in size or projection. But this is frequently difficult to do, hence the approximations.

Image rectification. A process by which the geometry of an image area is made planimetric. Image rectification doesn't remove relief distortion or perspective distortion.

Image resampling. A technique for geometric correction in digital image processing. Through a process of interpolation, the output pixel values are derived as functions of the input values combined with the computed distortion. Nearest neighbor, bilinear interpolation and cubic convolution are commonly used resampling techniques.

Image space. The mathematical space describing the position (coordinates) of pixels in the image.

Imaging array. A solid-state imaging array consists of a 1-D or 2-D set of photodetectors onto which an image can be focused, together with an integral electronic readout scheme. The devices are classified according to the particular readout scheme and detector type. A linear array is an imaging array consisting of a single line of detectors. The introduction of detector arrays has resulted in a new type of spectrometer – the imaging spectrometer – capable of generating images in much narrower bands (hyperspectral imagers) than was possible with conventional spectrometers.

Imaging sensors. Instruments that produce a 2-D image of the target area. Imaging sensor systems may be subdivided into 'framing systems' (such as camera or vidicon) and 'scanning systems.'

Imaging spectrometry. The simultaneous acquisition of images in many contiguous spectral bands.

Incidence angle (θ_i). Angle formed between the instantaneous line of measurement of a sensor to a target and the local vertical of the target (or object). Example: the backscatter of a radar instrument is a function of the incidence angle. In general, low incidence angles (perpendicular to the surface) will result in high backscatter; backscatter will decrease with increasing incidence angles.

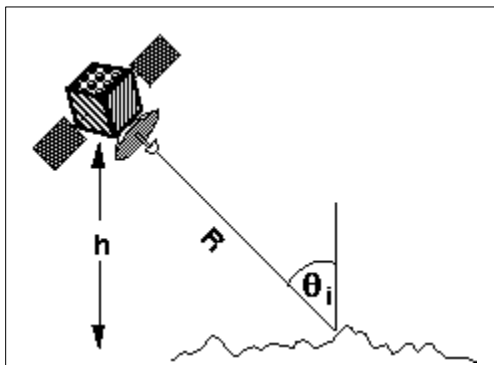


Figure 1589: Illustration of incidence angle θ_i of a SAR instrument

Inclination. In general the angle between two planes or their poles; usually the angle between an orbital plane and a reference plane (i.e. the equator plane). Inclination is one of the standard orbital elements specifying the orientation of the orbit plane (see also Q.10 on page 3567).

Information optics. A newly coined word at the start of the 21st century, referring to information technology in general; it is associated with the optics of detection, transport, storage and/or processing of information.

In-situ soundings. An observation method (using sensors on such platforms as aircraft, balloons, ships, buoys, towers, spacecraft, on the ground, etc.) with the objective to measure parameters in the immediate environment. From a historical point of view 'in-situ' observation predated 'remote' observation by ages. Thermometers, barometers, thermocouples, hygrometers, air samplers, etc. are in-situ sensors, as are in fact most sensors in the fields of meteorology, atmospheric chemistry, hydrology, etc. By far the largest percentage of ground-truth observations are in-situ measurements (i.e., measurements of parameters at a particular location and at a particular time). Remote sensing data of a particular sensor and target area may be compared (calibrated) against in-situ data of that target area. Spaceborne data collection systems, like ARGOS on polar orbiting satellites, remotely collect data from many thousands of 'in-situ measurement systems' in the ground segment on a routine basis. Examples of spaceborne in-situ observations are: sensors measuring magnetic or electric field parameters, solar wind particles, etc.

By their very nature, in-situ measurements are local measurements; hence, they offer a very low observation efficiency with regard to coverage and timeliness (repeat periods). It would take a fleet of spacecraft to obtain in-situ data with sufficient spatial and timely resolution on a global scale.

Instantaneous Field of View (IFOV). A term denoting the angular resolution of a single detector element (it is a measure of the target area viewed by a single detector). The IFOV may be expressed either as a small solid angle (in mrad or μ rad, in this case the value is independent of the orbital altitude of the sensor), or as a unit area (e. g. 6 m x 6 m), or simply as the pixel size. Hence, the IFOV actually represents the spatial resolution of a sensor measurement.

Integrated Molecular Circuit (IMC): The first IMC was created in mid–2013 by a group of chemists and physicists from the Department of Chemistry Nano–Science Center at the University of Copenhagen and Chinese Academy of Sciences, Beijing. Now for the first time, a transistor made from just one molecular monolayer has been made to work where it really counts — on a computer chip. The breakthrough was made possible through an innovative use of the two dimensional carbon material graphene. ^{6898) 6899)}

Integrated Water Vapor (IWP). IWP refers to the amount of water (usually measured in mm) that would result from condensing all of the water vapor in a column of air, extending from the Earth’s surface to the top of the atmosphere.

Integration time. Refers to the short time period allocated for the radiative measurement of the instantaneous area of observation by the detector of a sensor (see also **dwelt time**). Depending on sensor type the integration time may be very short [as is the case with electro-mechanical scanning systems which measure each individual cell (IFOV) across the swath sequentially], while the entire swath width (FOV) is measured by a CCD detector array in a single measurement.

Interference. Signals that arise from sources extraneous to the measurement system and result in errors in the measured value.

Interference filter. A filter reflecting radiation selectively in a narrow spectral band.

Interferogram. An image of interference phenomena such as phase differences (as patterns of interference fringes) measured by an interferometer, FTIR spectrometers, or generated by SAR interferometry. Interference fringes form through the interaction of two beams. Hence, for a given wavelength, the signal on the detector is either strong or weak. Two cases are of interest:

- Constructive interference. This occurs when the optical path difference (OPD) between the two light paths from the collectors to the detector is zero or a multiple of the observing wavelength
- Destructive interference. It occurs when the OPD is a half–integer number of wavelengths. The destructive interference is also referred to as ‘nulling mode’.

Interferometer. An instrument class for dispersing spectra. The technique determines the relative phase of two (or more) wave fronts of a coherent light wave as a function of spatial location by observing interference fringes. Radiation is split into two or more beams which traverse different path lengths. The beams are reflected by mirrors and recombined for interference analysis. (see chapter Q.9).

The interferometric method is based on the measurement of path length differences of the light reflected by the optical system (telescope, or reflector only) under test and the reference wavefront. A light wave reflected interferes with this reference wave. A camera records the fringe pattern (interferogram) that after some computations give the surface error. The measurement accuracy is a fraction of the operational wavelength ($\lambda/10$ to $\lambda/100$ rms).

Interlaced scanning. Refers to a subsampling readout technique from a detector array of a camera or from some other high data–rate instrument. The advantage of such a measure is to reduce the bandwidth for image transmission. However, the disadvantage is a delay in

6898) “Danish chemists in molecular chip breakthrough,” Space Daily, June 24, 2013, URL: http://www.spacedaily.com/reports/Danish_chemists_in_molecular_chip_breakthrough_999.html

6899) Tao Li, Martyn Jevric, Jonas R. Hauptmann, Rune Hviid, Zhongming Wei¹, Rui Wang, Nini E. A. Reeler, Erling Thyrrhaug, Søren Petersen, Jakob A. S. Meyer, Nicolas Bovet, Tom Vosch, Jesper Nygård, Xiaohui Qiu, Wenping Hu, Yunqi Liu, Gemma C. Solomon, Henrik G. Kjaergaard, Thomas Bjørnholm, Mogens Brøndsted Nielsen, Bo W. Laursen¹, Kasper Nørgaard, “Ultrathin Reduced Graphene Oxide Films as Transparent Top–Contacts for Light Switchable Solid–State Molecular Junctions,” *Advanced Materials*, Article first published online: 14 June, 2013, DOI: 10.1002/adma.201300607

total image recovery on the receiving side, resulting in distortions for fast moving objects in successive frames. The interlaced scanning technique is used for NTSC (National Television System Committee, a US TV display standard) television camera readout, in which each frame is scanned in two successive fields, each consisting of all the odd or all the even horizontal lines. The technique is also employed in other camera systems.

Intermediate frequency (IF). A common microwave frequency in an instrument (say, 80 MHz) for all channels at which considerable amplification takes place, interconnections are made, automatic gain adjustment is provided, and channels may be disabled upon command (squellch). The IF concept of a relatively low frequency is used to simplify the design of all functions compared to performing them at much higher frequencies in the GHz region.

International Polar Year (IPY): On three occasions over the past 125 years scientists from around the world banded together to organize concentrated scientific and exploring programs in the polar regions. In each major thrust, or “year,” scientific knowledge and geographical exploration were advanced, thereby extending understanding of many geophysical phenomena that influence nature’s global systems. Each polar year was a hallmark of international cooperation in science. The experience gained by scientists and governments in international cooperation set the stage for other international scientific collaboration. International scientific cooperation also paved the way for several political accords that gained their momentum from the polar years.⁶⁹⁰⁰⁾

- **First International Polar Year (1882–1883):** The idea of International Polar Years was the inspiration of the Austrian explorer and naval officer Lt. Karl Weyprecht who was a scientist and co–commander of the Austro–Hungarian Polar Expedition of 1872–74.

From his experiences in the polar regions Weyprecht became aware that solutions to the fundamental problems of meteorology and geophysics were most likely to be found near the Earth’s poles. The key concept of the first IPY was that geophysical phenomena could not be surveyed by one nation alone; rather, an undertaking of this magnitude would require a coordinated international effort. 12 countries participated, and 15 expeditions to the poles were completed (13 to the Arctic, and 2 to the Antarctic).

- **Second International Polar Year (1932–1933):** The International Meteorological Organization proposed and promoted the Second IPY (1932–1933) as an effort to investigate the global implications of the newly discovered “Jet Stream.” 40 nations participated in the Second IPY, and it heralded advances in meteorology, magnetism, atmospheric science, and in the “mapping” of ionospheric phenomena that advanced radioscience and technology. Forty permanent observation stations were established in the Arctic, creating a step–function expansion in ongoing scientific Arctic research. In Antarctica, the U.S. contribution was the second Byrd Antarctic expedition, which established a winter–long meteorological station approximately 125 miles south of Little America Station on the Ross Ice Shelf at the southern end of Roosevelt Island. This was the first research station inland from Antarctica’s coast.

- **The International Geophysical Year (1957–58):** The International Geophysical Year (IGY), 1 July 1957 to 31 December 1958, celebrated the 75th and 25th anniversaries of the First and Second IPYs. The IGY was conceived by a number of post–WWII eminent physicists, including Sydney Chapman, James Van Allen, and Lloyd Berkner, at an informal gathering in Washington, DC in 1950. These individuals realized the potential of the technology developed during WWII (for example, rockets and radar), and they hoped to redirect the technology and scientific momentum towards advances in research, particularly in the upper atmosphere. The IGY’s research, discoveries, and vast array of synoptic observations revised or “rewrote” many notions about the Earth’s geophysics. One long disputed theory, continental drift, was confirmed. A U.S. satellite discovered the Van Allen Radiation Belt encircling the Earth.

⁶⁹⁰⁰⁾ “A Short History of IPY,” May 1, 2009, URL: <http://classic.ipy.org/development/history.htm>

- Third International Polar Year (2007–2008): The concept of the International Polar Year 2007–2008 is of an international program of coordinated, interdisciplinary scientific research and observations in the Earth's polar regions:

- to explore new scientific frontiers
- to deepen our understanding of polar processes and their global linkages
- to increase our ability to detect changes, to attract and develop the next generation of polar scientists, engineers and logistics experts
- to capture the interest of schoolchildren, the public and decision-makers.

GIIPSY (Global Interagency IPY Polar Snapshot Year)⁶⁹⁰¹⁾ ⁶⁹⁰²⁾ ⁶⁹⁰³⁾ is a WMO/ICSU (World Meteorological Organization/International Council of Scientific Unions) approved IPY Project (Project #91) whose objective is to obtain high-definition satellite snapshots of the polar regions during 2007–2008. The primary purpose is to use these snapshots as benchmarks for gauging past and future environmental changes in the polar ice, ocean, and land. In the spirit of IPY, the project also seeks to secure these data sets as our legacy to the next generations of polar scientists.

Interplanetary magnetic field. Designates the magnetic field carried out from the sun by the solar wind, which permeates the entire heliosphere.

Intertropical convergence zone. A low pressure trough and minimum east wind, lying between the trade regions of the two hemispheres, that are nearly continuous around the world on climatological charts.

Inversion (atmosphere). A positive temperature gradient or increase in temperature with elevation, resulting in adverse conditions for the dispersion of pollutants.

Ionograms. Ionograms are recorded tracings of reflected high frequency radio pulses generated by an ionosonde. Unique relationships exist between the sounding frequency and the ionization densities which can reflect it. As the sounder sweeps from lower to higher frequencies, the signal rises above the noise of commercial radio sources and records the return signal reflected from the different layers of the ionosphere. These echoes form characteristic patterns or "traces" that comprise the ionogram. Radio pulses travel more slowly within the ionosphere than in free space, therefore, the apparent or "virtual" height is recorded instead of a true height. For frequencies approaching the level of maximum plasma frequency in a layer, the virtual height tends to infinity, because the pulse must travel a finite distance at effectively zero speed. The frequencies at which this occurs are called critical frequencies. Characteristic values of virtual heights (designated h'E, h'F, and h'F₂, etc.) and critical frequencies (designated foE, foF₁, and foF₂, etc.) of each layer are scaled, manually or by computer, from these ionograms.

Ionosphere. Layer of the Earth's atmosphere, between approximately 60 and 1000 km in altitude (a highly variable and complex physical system), that is partially ionized by solar x-rays, ultraviolet radiation, and energetic particles from space. The process of ionization is controlled by chemical composition and transport by diffusion and neutral wind. The region between about 160 to 1000 km, known as the F-region of the ionosphere; it contains the greatest concentration of electrons (the peak electron concentration is around 250–300 km). The presence of the ionized zone disturbs the propagation of electromagnetic waves,

6901) Mark R. Drinkwater, Kenneth C. Jezek, Jeff Key, "Coordinated Satellite Observations during the International Polar Year: Towards Achieving a Polar Constellation," 2008, URL: http://bprc.osu.edu/rsl/GIIPSY/documents/SRT_IPY-Drinkwater_Jezek_Key.pdf

6902) Rod Franklin, "GIIPSY: A Flagship Project of the IPY and Contributor to GEOSS," Imaging Notes, Spring 2008, Vol. 23, No 1, URL: <http://bprc.osu.edu/rsl/GIIPSY/documents/giipsy.pdf>

6903) "Polar scientists herald importance of satellite observations," ESA, June 15, 2010, URL: http://www.esa.int/esaCP/SEMETLOVEAG_index_0.html

particularly at the lower wave frequencies. Below a certain frequency, the wave may be totally reflected by the ionosphere. – At times, the F–region of the ionosphere becomes disturbed and small–scale irregularities develop. When sufficiently intense, these irregularities scatter radio waves and generate rapid fluctuations (or scintillation) in the amplitude and phase of radio signals.

The Earth’s ionosphere is important for a wide range of communication systems: including high frequency radio, satellite control activities, search and rescue activities, cell phones and pagers, and navigation systems. For instance, the ionosphere reflects radio waves, allowing shortwave radio operators to bounce transmissions over the horizon for long–range communications. The ionosphere also bends and scatters signals from satellites transmitting their data to the ground or uplinking data to the spacecraft (including GPS satellites). – The ionosphere also plays host to the largest lightshow on Earth, the aurora.

The ionosphere was discovered in the early 1900s when radio waves were found to propagate “over the horizon.” If radio waves have frequencies near or below the plasma frequency, they cannot propagate throughout the plasma of the ionosphere and thus do not escape into space; they are instead either reflected or absorbed. At night the absorption is low since little plasma exists at the height of roughly 100 km where absorption is greatest. Thus, the ionosphere acts as an effective mirror, as does the Earth’s surface, and waves can be reflected around the entire planet much as in a waveguide.

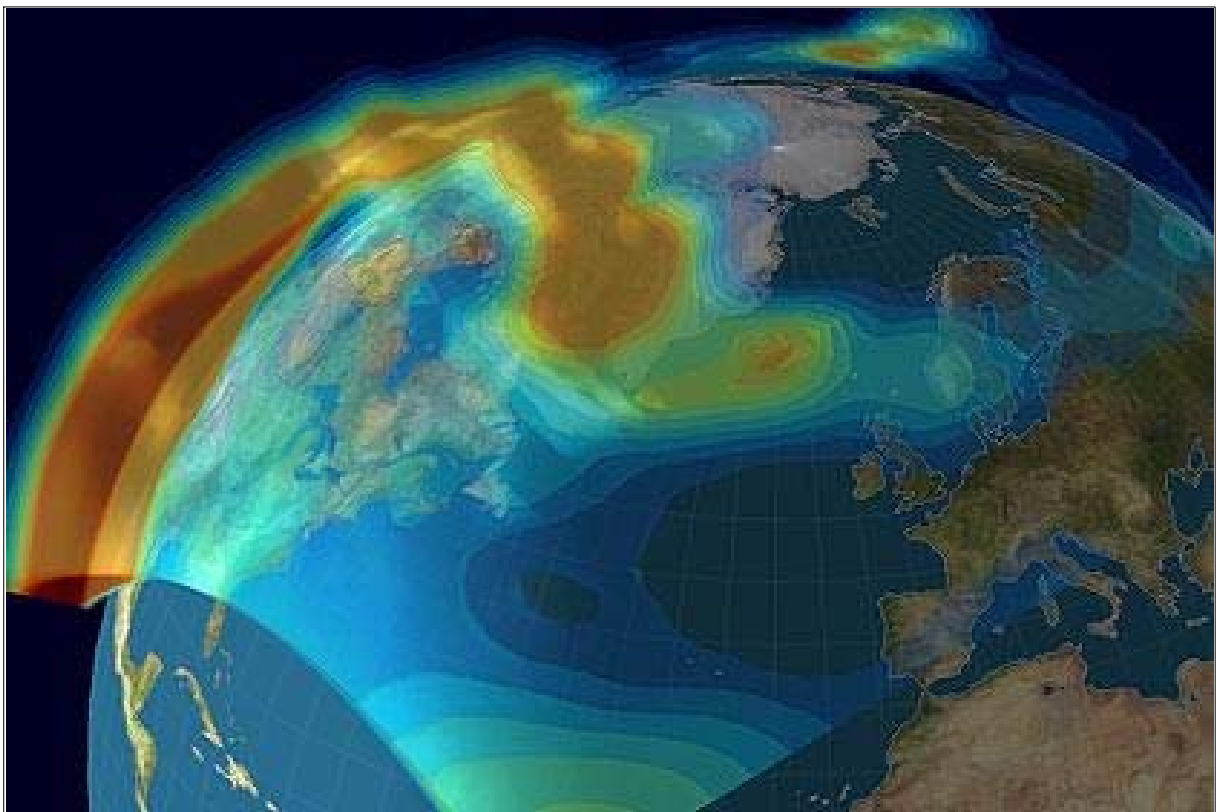


Figure 1590: Artist’s rendition of an auroral display (image credit: NASA)

Ionospheric disturbances. Refer to transient changes in ionospheric densities or currents, or the appearance of electron density irregularities, usually in association with the arrival of x–rays or UV bursts from solar flares.

Ionospheric regions. The ionosphere is divided into four broad regions called D, E, F, and topside. These regions may be further divided into several regularly occurring layers, such as F1 or F2.

- **D Region:** The region between about 75 and 95km above the Earth in which the (relatively weak) ionization is mainly responsible for absorption of high–frequency radio waves.

- **E Region:** The region between about 95 and 150km above the Earth that marks the height of the regular daytime E layer. Other subdivisions isolating separate layers of irregular occurrence within this region are also labeled with an E prefix, such as the thick layer, E2, and a highly variable thin layer, Sporadic E. Ions in this region are mainly O₂⁺.
- **F–Region (or F–layer):** The F–Layer constitutes the highest region, ranging from about 160–500 km. Some sublayers within the F–region are: F1 (temperate–latitude regular stratification layer), F1.5 (a semi–regular stratification layer occurring at low latitudes), and F2 (the reflection layer important for radio communications). Within the F–Layer precipitating electrons from the magnetosphere cause ionization critical to long–wave radio communication. This ionization is typically caused by electrons with a kinetic electron energy < 1 keV. Ionization within the F–Layer may be characterized by sensors designed to measure UV radiation. F–Layer electron density is usually two to four orders of magnitude higher than that of the D– and E–Layers.

Layer	Altitude	Major Components	Production Cause
D	70 – 95 km	NO ⁺ , O ₂ ⁺	Lyman Alpha, X–rays
E	95 – 160 km	O ₂ ⁺ , NO ⁺	Lyman Beta, Soft X–rays, UV continuum
F	160 – 500 km	O ⁺ , N ⁺ , NO ⁺	HE II, UV continuum
Topside	> 500 km		

Table 971: Ionospheric layers and physical causes of ionization

Irradiance. Refers to radiative energy per unit time (power) impinging on a surface, normalized by the surface area, and is typically specified in watt per square meter (W/m²).

Isotropic radiator (antenna). A theoretical radiator of infinitesimal size in which it is assumed that all energy is distributed evenly (point source). Such a concept serves as a reference for other antennas of finite dimensions.

Kessler Syndrome. The Kessler Syndrome is a theory proposed by NASA scientist Donald J. Kessler in 1978, used to describe a self–sustaining cascading collision of space debris in LEO (Low Earth Orbit). It’s the idea that two colliding objects in space generate more debris that then collides with other objects, creating even more shrapnel and litter until the entirety of LEO is an impassable array of super swift stuff. At that point, any entering satellite would face unprecedented risks of headfirst bombardment. ⁶⁹⁰⁴⁾

Lambertian radiator. A target or an object having the radiative property of directional independence of its (emitted and reflected) energy. With respect to reflection the object or target may be regarded to be a diffusely reflecting surface.

Langmuir probe. An instrument employed to measure the current–voltage characteristics of a plasma (single and double probes are in use) in order to determine plasma density.

Laplacian filter. A linear window operation (digital filter) concerning second derivatives of the pixel values within a window, either unidirectional or bidirectional (orthogonal).

Laser (Light Amplification by Stimulated Emission of Radiation). A source of light that is highly coherent (spatially and temporarily) and emitted in one or more wavelengths. A typical laser consists of two essential elements: gain and feedback. A beam of light passing through the gain, or amplifying, medium stimulates it to release its stored energy in the form of additional light that adds to, or amplifies, the beam. Feedback is achieved by placing the gain medium within the resonator (a set of mirrors that reflects the beam back and forth through the gain medium). The light from such a laser is composed of a number of discrete

6904) Donald J. Kessler, Burton G. Cour–Palais, “Collision Frequency of Artificial Satellites: The eC reation o f a Debris Belt, Journal of Geophysical Research, Vol. 83, No A6, June 1, 1978, URL: <http://webpages.charter.net/dkessler/files/Collision%20Frequency.pdf>

wavelengths corresponding to different resonant frequencies, or modes, of the resonator. There are two groups of lasers which operate either in a pulsed mode or in a continuous mode. The spectral range of lasers extends from the UV to the TIR (90 nm to 12 μm).

Historically, the laser was an extension of the maser (microwave amplification by stimulated emission of radiation), a microwave oscillator developed by N. G. Basov and A. M. Prokhorov in the USSR and C. H. Townes in the USA (1954). In 1958, C. H. Townes and A. L. Schawlow proposed extending the maser principle into the optical regime. They pointed out that an interferometer of the type developed by Fabry and Perot in 1900 would also function as an optical resonator.⁶⁹⁰⁵⁾

The first working laser was demonstrated in May 1960 by **Theodore H. Maiman**,⁶⁹⁰⁶⁾ a physicist at Hughes Electric Corporation (Hughes Research Laboratories) in CA, USA. Maiman developed a laser that was made out of ruby, which has a high chromium content, and absorbs green and blue light while emitting red light. By flashing white light into a cylinder of ruby, Maiman energized the electrons in the chromium. The energized green and blue wavelengths were absorbed and then amplified the red wavelengths until the light pulse of the ruby was amplified to high power, resulting in a laser. This event represented a major breakthrough in the field of applied physics.

By 1961, the first commercial laser hit the market. Laser technology increased as rapidly as the commercial laser industry. Fast on the heels of Maiman's laser came the dye laser, the helium–neon laser, the semi–conductor laser, the carbon–dioxide laser, the ion laser, the metal–vapor laser, the excimer laser, and the free–electron laser.

Since then, the laser impact has rippled through numerous industries (medicine, industry, electronic, data processing, communications and scientific research) in a myriad of ways and has revolutionized life. It brings, sends and stores data in vast batches at light speed, measures material and cuts it with sub–millimetric precision. Lasers drive the CD (Compact Disk) and DVD player. The era of modem spectroscopy began with the invention of the laser.

Types of lasers:⁶⁹⁰⁷⁾

- **Gas lasers:** Usually receive their energy input via collisions of gas atoms with high–energy electrons. This energy is provided by applying a high voltage between electrodes located within the gaseous medium. The most common types of gas lasers are:
 - **He–Ne laser:** Uses a gas discharge of helium and neon as the gain medium (this was the first laser to emit a continuous output beam).
 - **Argon and krypton ion laser:** Uses a gas discharge containing ions as a gas medium. First lasers to operate in the blue and green regions of the spectrum.
 - **CO₂ laser:** One of the most powerful lasers, operating mostly in the spectral region of about 10.5 μm . They range from small versions with a few mW of continuous power to large pulsed versions.
 - **TEA (Transverse Excitation–Atmospheric pressure):**⁶⁹⁰⁸⁾ These are generally pulsed CO₂ lasers; both the gas flow (about 1 atmosphere) and the electric discharge are transverse to the optical axis. Such conditions yield tremendous population inversions for short times. Commercially available TEA lasers deliver 100 to 200 ns pulses of several Joules/pulse at a repetition rate of 50 Hz; they are used for welding and cutting.

⁶⁹⁰⁵⁾ <http://en.wikipedia.org/wiki/Laser>

⁶⁹⁰⁶⁾ “Theodore Maiman and the Laser,” URL: http://www.ieeeeghn.org/wiki/index.php/Theodore_Maiman_and_the_Laser

⁶⁹⁰⁷⁾ Encyclopedia of Physical Science and Technology, Academic Press, 1987, Vol. 7 pp. 153–160

⁶⁹⁰⁸⁾ Courtesy of L. Zink of NIST, Boulder, CO

- **Rare–Gas–Halide excimer laser:** Operate primarily in the UV region in mixtures of rare gases, such as argon, krypton or xenon, with halide molecules such as chlorine and fluorine.
- **Chemical lasers:** In these lasers the molecules undergo a chemical reaction. The hydrogen–fluoride laser fits into this class.
- **Metal Vapor lasers:** These lasers are actually a type of gaseous laser, since the laser action occurs in the atomic or molecular vapor phase of the species. The two best–known types are the helium–cadmium ion laser and the pulsed copper vapor laser.
- **Solid–State lasers:** These laser generally consist of transparent crystals or glasses as “hosts” within which ionic species of laser atoms are interspersed or ‘doped.’ Typical host materials include aluminum oxide (sapphires), garnets, and various forms of glasses, with the most common lasing species being neodymium ions and ruby ions. – The energy input in these lasers is provided by a light source that is focused into the crystal to excite the upper laser levels. The light source is typically a pulsed or continuously operating flash lamp.
- **Nd:YAG laser:** A laser whose gain medium consists of a neodymium–doped yttrium aluminum garnet crystal. The laser emits in the NIR region at 1.06 μm .
- **Ruby laser:** This laser is produced by implanting chromium ions into an aluminum oxide crystal host and then irradiating the crystal with a flash lamp to excite the laser levels.
- **Color center laser:** This laser uses a different form of impurity species implanted in a host material (usually one part per ten thousand). Color lasers typically operate in the 0.8 – 4 μm region and are tunable by using different crystals having different emission wavelengths.
- **Semiconductor lasers:** Semiconductor or diode lasers are the smallest lasers yet devised (about the size of a grain of salt). They consist of a p–n junction formed in an elongated gain region, typically in a gallium–arsenide crystal, with parallel faces at the ends to serve as partially reflecting mirrors. The light output of semiconductor lasers can be directly modulated using bias current, they can be tuned in wavelength using both temperature and bias current. Semiconductor diode lasers range in wavelength from 0.7 to 1.8 μm with typically continuous output power of up to 10 mW. Two types of semiconductor diode lasers are in wide use: ⁶⁹⁰⁹⁾
- **EEL (Edge–Emitting Laser).** A horizontal–cavity laser with an optical output beam emitting from the edge of the laser chip.
- **VCSEL (Vertical–Cavity Surface–Emitting Laser).** A VCSEL’s cavity is perpendicular to the wafer plane (the beam is guided in the vertical direction). The VCSEL is used for wavelength engineering, in optical fiber communications, etc.

6909) C. J. Chang–Hasnain, “VCSELs Advances and Future Prospects,” Optics & Photonics News, May 1998, pp. 34–39

Parameter	Laser type	Wavelength (nm)	Energy range
CW (Continuous Wave)	Argon Ion	488 and 514	1 μ W to about 1 W
	He–Ne	633	1 μ W to about 20 mW
	Diode	830	100 μ W to about 20 mW
	Nd:YAG	1064	100 μ W to about 450 W
		1319	100 μ W to about 10 mW
	HeNe	1523	100 μ W to about 1 mW
CO ₂	10600 (or 10.6 μ m)	1 μ W to about 1 kW	
Pulsed	KrF Excimer	248	10 ⁻³ to about 200 mJ/pulse 50 μ W – 9W average power
	ArF Excimer	193	10 ⁻³ – 3 mJ/pulse 50 μ W – 3 W average power
	Nd:YAG	1064	1 – 50 mJ/pulse 10 nW – 100 μ W 10 ⁻³ – 10 nJ/pulse

Table 972: Overview of some laser characteristics ⁶⁹¹⁰⁾

– **Quantum cascade laser (QC laser).** ⁶⁹¹¹⁾ Refers to a laser–based semiconductor sensor that operates at room temperature and at high power to detect minute amounts of trace gases (ppb) or pollutants by scanning for their optical–absorption “fingerprints.” The lasers’ high peak power, of 50–60 mW at 300 K, allows the use of uncooled detectors and enables LIDAR applications. They are particularly well suited for portable, robust sensors in applications such as the point detection of trace gases and remote sensing applications.

The QC laser technology was invented by Jerome Capasso, Jerome Faist, Sivco, Carlo Sirtori, Hutchinson and Cho of Bell Labs (Murray Hill, NJ) in 1994, who demonstrated continuously tunable, single–mode, QC distributed–feedback lasers operating at mid–infrared wavelengths (5 and 8.5 μ m) in pulsed mode. The single–mode tuning range is typically 50 nm in wavelength, and the peak powers are 60 mW.

QC lasers are made using the technique of MBE (Molecular Beam Epitaxy), featuring layered structures of only a few atoms thick. The QC laser’s emission wavelength is determined initially by quantum–confinement effects: the fact that its layers are so thin that electrons are squeezed and change their quantum–mechanical properties, allowing a range of possible wavelengths. The distributed–feedback lasers incorporate a grating that makes it possible to further refine the laser’s wavelength, making them continuously tunable. – The operation of a QC laser is unlike that of other laser types. They operate like an electronic waterfall: when an electric current flows through a QC laser, electrons cascade down an energy staircase; every time they hit a step, they emit an infrared photon. At each step, the electrons make a quantum jump between well–defined energy levels. The emitted photons are reflected back and forth between built–in mirrors, stimulating other quantum jumps and the emission of other photons. This amplification process enables high output power.

Bell Labs has built built QC lasers operating throughout the mid–infrared region from 4.5 to 11.5 μ m in both pulsed mode at room temperature and in continuous wave (CW) mode at temperatures up about 110 $^{\circ}$ C.

- **Liquid (dye) lasers:** Dye lasers are similar to solid–state lasers in that they use a host material in which the laser (dye) molecules are dissolved. Different dyes have different emission spectra or colors, thus allowing dye lasers to cover a broad wavelength range (320 – 1500 nm). A unique property of dye lasers is the broad emission spectrum (typically 30–60 nm) over which gain occurs. The dye laser is tunable over a frequency range of 10¹³ Hz.

– **Dye laser:** Laser in which the gain medium consists of an organic dye dissolved in a liquid solvent. Applications in areas where tunability of the laser frequency is required. Dye

6910) M. Dowell, “Pulsed–Laser Metrology at NIST,” Optics&Photonic News, Feb. 2001, pp. 30–33

6911) <http://www.bell-labs.com/news/1997/may/21/4.html>

lasers are also used for producing ultra–short pulses, a technique which is referred to as ‘mode–locking.’

- **Free–Electron lasers:** These lasers are significantly different from any other type of laser in that the laser output does not result from discrete transitions in atoms or molecules of gases, liquids, or solids. Instead, a high–energy beam (in the order of 1 MeV) of electrons is directed to pass through a spatially varying magnetic field that causes the electrons to oscillate in a direction transverse to their beam direction. This laser type can be used over a wide range of wavelengths from the UV to FIR.

Laser cooling. The technology of laser cooling began with the development of a set of tools using laser beams to slow atoms down, cooling them to within a millionth of a degree above absolute zero (the atoms actually relinquish their heat energy to laser light and thus reach lower and lower temperatures). At these cold temperatures, cesium atoms are left with a residual velocity of only 1 cm/s. This slowing of atoms allows scientists a longer observation time to study the atoms’ behavior. When a laser–cooled vapor (like cesium) is taken to microgravity, the observation time is increased considerably because the cold and slow atoms will not fall out of the observer’s view as quickly as they do under the influence of the Earth’s gravity. The small residual velocity makes for instance cesium atoms attractive candidates for precision spectroscopy in atomic clocks.

Laser cooling techniques have also been used to cause a cloud of atoms to condense into the Bose–Einstein ⁶⁹¹²⁾ state, a new state of matter similar to superfluid helium. The BEC (Bose–Einstein Condensate) occurs when atoms at a particular temperature and pressure, on the removal of some energy, fall into lock–step with one another.

Background: Normally, light appears to heat things up (through absorption of light by the material). However, it is possible, in some cases, to use light to cause materials to give up more energy than they absorb, causing them to cool. Basic research with laser cooling of atoms was first done in the 1980s by Steven Chu of Stanford University, Claude Cohen–Tannoudji of College de France, and William D. Phillips of NIST (National Institute of Standards and Technology), Gaithersburg, MD. For this work they were awarded the 1997 Nobel Prize in Physics.

Layman–alpha radiation. The radiation emitted by hydrogen at 1,216 Å, first observed in the solar spectrum by rocket–borne spectrographs.

Leads. Leads are transient areas of open water and/or very new ice, created in response to convergence/divergence phenomena (deformation processes) in the polar ice pack (see also **nilas**).

Limb/Occultation sounding. A horizon–looking (or edge–looking i.e. outer edge of the apparent disk of a celestial body) observation technique that uses a distant object [(for occultation sounding) sun, star, or a sensor on another satellite in a different Earth orbit, (see Figure 1506)] as a source to observe the signal on its path through the atmosphere that is essentially tangential to the Earth’s surface. Two types of occultation techniques have been used in the past to determine the composition and structure of the atmosphere:

- 1) **Extinctive occultations:** These occur because atmospheric constituents absorb or scatter the incoming radiation. Since extinction cross sections are generally wavelength–dependent, spectral measurements – as the star (sun) sets deeper into the atmosphere – are diagnostic of the atmospheric composition. Hence constituent profiles may be determined from the relative transmission (i.e., the ratio of occulted to un–occulted spectra). As a result, extinctive occultation measurements are self–calibrating and ideal for long–term trend monitoring. – The technique provides measurements that are commonly referred to

⁶⁹¹²⁾ Note: The Bose–Einstein condensate is a purely quantum form of matter, first predicted by Einstein and the Indian physicist Satyendra Nath Bose in 1924, but for the first time created and observed in a laboratory by scientists in the University of Colorado in 1995. This work led to the 1997 Nobel Prize in Physics.

as trace gas monitoring. Examples of spaceborne instruments employing extinctive occultations are: SAGE (AEM-2, ERBS, Meteor-3M, ISS), POAM (SPOT-3,4,5), HALOE (ATLAS-1,2), ATMOS (ATLAS-1, Spacelab-3), ILAS (ADEOS, ADEOS-II), and GOMOS (ENVISAT).

2) **Refractive occultations:** They occur because density gradients in the atmosphere lead to refraction of the incoming radiation, causing it to follow curved paths through the atmosphere. Relative measurements of the degree to which the path of the incoming radiation is changed provide the bulk of atmospheric properties (density, pressure, temperature). Usually, this occultation technique employs dual-frequency carrier-phase observations of retarded signals (atmospheric propagation delays) from GPS or GLONASS satellites which permit the derivation of atmospheric profiles of density, pressure, and temperature. The GPS/MET instrument of Microlab-1 and TRSR (TurboRogue Space Receiver) of CHAMP, SUNSAT, and other missions are examples of refractive radio occultation monitoring.

Very long atmospheric paths (up to 4000 km) with high sensitivities or dynamic ranges can be obtained in this 'limb-sounding' configuration. The refractive technique takes advantage of the precise knowledge of GPS satellite positions and timing of GPS radio signals. Instruments like GPS/MET and TRSR measure the extra time it takes for a GPS signal to enter Earth's atmosphere obliquely, pass through, and re-emerge to strike the LEO S/C – compared to an otherwise un-refracted direct ray path. The time delays of the GPS signal due to such atmospheric passage during the course of the occultation are used to derive the corresponding bending angles of the ray path, which in turn are converted to the refractive index profile of the atmosphere. Note: The time delay is proportional to the TEC (Total Electron Content) in the ionosphere along the path of the GPS signal (the electron content varies with location).

Some key advantages of limb sounding are:

- It maximizes the reception of the signal emitted by the atmospheric layer at the viewed tangent height provided that the receiver antenna has a very narrow beam
- The background temperature (that of the deep space) is much colder than that of the atmosphere, which guarantees very low biasing of the measured atmospheric emissions
- Vertical profiles with a high resolution can be obtained by limb scanning with a very narrow antenna beam
- A global coverage is achieved with LEO polar orbiting satellites.

A major disadvantage of limb sounding is: Low horizontal resolution due to the measurement geometry (long path-length) and high speed of the spacecraft (signal integration along the moving tangent point).

Lithosphere. Earth's outer rigid crust (or outermost shell) composed of rocks rich in silicon, aluminum, calcium, sodium, potassium, and some other elements, and hence less dense than the underlying mantle. The lithosphere varies from less than 30 km thickness under the ocean to over 100 km under continents.

Local oscillator (LO). A receiver oscillator that produces a reference sinusoid for comparison with the noisy received sinusoid.

Look angle. The direction in which an antenna is pointing when transmitting and receiving from a particular cell (for an active instrument). Refers to the instrument pointing direction from nadir. – In the current literature the terms 'look angle,' 'illumination angle,' 'pointing angle,' 'off-nadir angle,' and 'viewing angle' all have the same meaning.

Looks (in SAR imagery) see chapter Q.8.5 on page 3555.

LORAN (Long–Range Navigation), see chapter 1.29.1.

Lorentz force (named after the Dutch physicist Hendrik Lorentz, 1853–1928). Refers to the force exerted on a charged particle in an electromagnetic field. The particle will experience a force due to electric field of $q\mathbf{E}$, and due to the magnetic field $q\mathbf{v} \times \mathbf{B}$. Combined they give the Lorentz force equation (or law): $\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$, where:

- \mathbf{F} is the force (N)
- \mathbf{E} is the electric field (V/m)
- \mathbf{B} is the magnetic field (Weber/m²)
- q is the electric charge of the particle (coulomb)
- \mathbf{v} is the instantaneous velocity of the particle (m/s)

Hence, a positively charged particle will be accelerated in the same linear orientation as the \mathbf{E} field, but will curve perpendicularly to the \mathbf{B} field according to the right–hand rule. – Example: An electrodynamic tether exploits the magnetic field of a planet via the Lorentz force acting on it when the tether is transversed by a current. In order for the concept to work the current flow in the tether needs to be closed using the plasma surrounding the satellite.

Low Noise Amplifier (LNA). A preamplifier between antenna and receiver. It is usually attached directly to the antenna receive port. Its main function is to reduce the thermal noise of the received signal.

LOWTRAN. LOW–resolution TRANsmittance – a computer code (model of USAF Geophysics Laboratory, also referred to as AFGL, Hanscom AFB, MA) which predicts the atmospheric transmittance and thermal radiation emitted by the atmosphere and the Earth. LOWTRAN programs are applicable for wave numbers ranging from 350 cm^{–1} (28.5 μm) in the infrared to 40,000 cm^{–1} (0.25 μm) in the UV region. The LOWTRAN code calculates atmospheric transmittance and radiance, averaged over 20 cm^{–1} intervals in steps of 5 cm^{–1}. The succeeding models are more advanced, building on the capabilities and options of the previous LOWTRAN models.⁶⁹¹³⁾

- LOWTRAN–2 (1972)
- LOWTRAN–3 (1975)
- LOWTRAN–3B (1976)
- LOWTRAN–4 (1978)
- LOWTRAN–5 (1980)
- LOWTRAN–6 (1983) includes solar/lunar scattering, new spherical refractive geometry subroutines, and an improved water vapor continuum model. Other modifications include a wind–dependent maritime aerosol model, a vertical structure aerosol model, a cirrus cloud model, and a rain model.
- LOWTRAN–7 (1988). This code has been extended to include the microwave spectral region.
- MODTRAN (1989)⁶⁹¹⁴⁾ (MODERate–resolution LOWTRAN). MODTRAN is an extended version of LOWTRAN–7 (six additional subroutines) to increase its spectral resolution from 20 cm^{–1} to 2 cm^{–1} (FWHM). Further objectives were: a) to model molecular absorption of atmospheric molecules as a function of temperature and pressure; b) to calculate band model parameters for twelve LOWTRAN molecular species; c) to integrate

⁶⁹¹³⁾ F. X. Kneizys, et al., “Atmospheric transmittance/radiance: computer code LOWTRAN–6, Report AFGL–TR–83–0187, Bedford, MA, NTIS Report ADA137786

LOWTRAN–7 capabilities into the new algorithms, maintaining compatibility with the multiple scattering option. For MODTRAN, molecular absorption is calculated in intervals of 1 cm^{-1} bins, the other parts of the calculation remain unchanged. The molecular species affected are: water vapor, carbon dioxide, ozone, nitrous oxide, carbon monoxide, methane, oxygen, nitric oxide, sulfur dioxide, nitrogen dioxide, ammonia, and nitric acid. The MODTRAN spectral region is from $0 - 17,900 \text{ cm}^{-1}$ (with 2 cm^{-1} spectral resolution), calculations at larger wave numbers, i.e. the VIS and UV regions, are performed at the lower spectral resolution of 20 cm^{-1} .

Magnetar. A magnetar is a type of neutron star which possesses an intense magnetic field, often in the range of 10 GT (gigatesla) – quadrillions of times more powerful than the magnetic field around the Earth and millions of times more powerful than any man–made magnets. As the magnetic field decays, it emits high intensity electromagnetic radiation in the form of X–rays and gamma rays. ⁶⁹¹⁵⁾

The first recorded bursts believed to come from a magnetar was observed in 1979. The primary theory of magnetar operation was presented in 1992 by Robert Duncan and Christopher Thompson to explain this and other observed phenomena.

In 2010, astronomers have probed a curious source, using the XMM–Newton and other world–class X–ray telescopes. The sources emit flares and bursts just like a magnetar but lacks the extremely high external magnetic field typical of these objects. The detection of this source, which could be powered by a strong, internal magnetic field hidden to observations, may mean that many 'ordinary' pulsars are dormant magnetars waiting to erupt. ⁶⁹¹⁶⁾

Magnetometer. An instrument (magnetic compass) for measuring the direction and strength of Earth's magnetic field. There are several types magnetometers:

- Mechanical magnetic compasses
- Fluxgate compasses
- Hall–effect compasses
- Magneto-resistive compasses
- Magneto-elastic compasses

Magnetopause. The surface defining an interface between the magnetic field of a star and matter in the disk; a surface where the average magnetic pressure of the magnetic field is in pressure balance with the plasma pressure. Earth's magnetopause is the region in the ionosphere where the magnetosphere meets the solar wind (see Figure 231).

Magnetosphere. The region of space surrounding a rotating, magnetized sphere. Specifically, the outer region of the Earth's ionosphere, starting at about 1000 km above Earth's surface and extending to about 60,000 km (or considerably farther, such as $100 R_E$ on the side away from the Sun).

Marginal ice zone (MIZ). The critical region in which polar air masses, ice, and water masses interact with the temperate ocean and climate systems (an important geophysical boundary zone involving energy exchanges). The transition zone is characterized by large horizontal gradients in the properties of the ice, ocean, and atmosphere.

Maser. An amplifier utilizing the principle of 'microwave amplification by stimulated emission of radiation.'

6914) A. Berk, L. S. Bernstein, D. C. Robertson, "MODTRAN: A moderate resolution model for LOWTRAN–7," AFGL–TR–89–0122, Air Force Geophysics Laboratory, Hanscom AFB, MA

6915) <http://physics.about.com/od/glossary/g/magnetar.htm>

6916) "Are most pulsars really magnetars in disguise?," ESA, Oct. 14, 2010, URL: <http://sci.esa.int/science–e/www/object/index.cfm?fobjectid=47844>

Maunder Minimum (solar physics), named after the English astronomer Edward Walter Maunder (1851–1928). Maunder is best remembered for his study of sunspots and the solar magnetic cycle that led to his identification of the period from 1645 to 1715 that is now known as the *Maunder Minimum*. Maunder studied solar records of the period (1645–1715) and discovered, that only a few sunspots during one 30 year period were observed (about 50) as compared to a more typical number of 40,000–50,000 spots. The Maunder Minimum coincided with the middle – and coldest part – of the so-called ‘Little Ice Age’, during which Europe and North America, and perhaps much of the rest of the world, were subjected to bitterly cold winters.

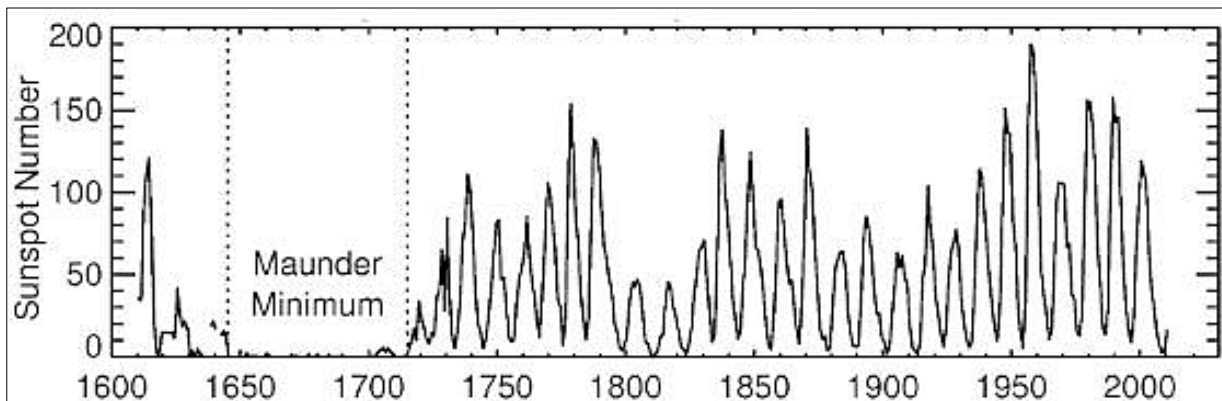


Figure 1591: Yearly averaged sunspot number for a period of 400 years (image credit: NASA/MSFC)⁶⁹¹⁷⁾

Measurement mode – duty cycle. The fraction of available time during which an instrument is actively performing Earth measurements and producing meaningful data, including incidental calibration and overhead (such as scan retrace). High data rate, high power consumption, and steerable instruments may have small duty cycles. Daylight-only instruments may have measurement mode duty cycles averaging 50 percent.

Medium Earth Orbit (MEO). Refers to all satellite orbits between LEO and GEO. MEO orbits have larger and longer footprints than LEO orbits. Navigation systems, like GPS and GLONASS, are examples of MEO orbits. MEO orbits are also attractive to a number of communication satellite networks due to their relatively small transmission delay times (in the order of 0.1 s). The shorter radial distance (compared to GEO) translates into improved signal strength at the ground which means better reception and ultimately smaller terminals.

Mesosphere. Region of the atmosphere between approximately 50 and 85 km in altitude.

Meteoroid. A small particle in space (sources are comets, detritus from asteroid collisions, and interstellar dust). A meteoroid that survives the passage through the Earth’s atmosphere and reaches the Earth’s surface is known as a “meteorite”.

- On Feb. 15, 2013, a large meteoroid (estimated at 15–18 m in diameter and 7000–10,000 tons in mass) made an unexpected visit over Russia to become the biggest space rock to enter the atmosphere since the Tunguska impact in 1908. The meteoroid, also referred to as meteor, that boomed over the city of Chelyabinsk, was big enough to survive its last trip around the Sun and sprinkle the ground with meteorites.⁶⁹¹⁸⁾

Travelling at a speed of 18 km/s, the meteoroid quickly became a brilliant fireball as it passed over the southern Ural region, exploding in an air burst over Chelyabinsk. The atmosphere absorbed most of the released energy, which was equivalent to nearly 500 kilotons of TNT making it 20–30 times more powerful than either of the atomic bombs detonat-

6917) “The Sunspot Cycle,” NASA/MSFC, Jan. 02, 2013, URL: <http://solarscience.msfc.nasa.gov/SunspotCycle.shtml>

6918) Bob King, “Russian Fireball Inspires Journey into the World of Meteorites,” Universe Today, Feb. 24, 2013, URL: <http://www.universetoday.com/100192/russian-fireball-inspires-journey-into-the-world-of-meteorites/>

ed at Hiroshima and Nagasaki. About 1,500 people were injured. Over 4,300 buildings in six cities across the region were damaged by the explosion. ^{6919) 6920)}

Scientists at Urals Federal University in Yekaterinburg examined 53 small meteorite fragments deposited around a hole-in-ice-covered Chebarkul Lake 77 km west of Chelyabinsk the following day. Chemical analysis revealed the stones contained 10% iron-nickel metal along with other minerals commonly found in stony meteorites. Since then, hundreds of fragments have been dug out of the snow by people in surrounding villages (Ref. 6918). ⁶⁹²¹⁾



Figure 1592: The two main smoke trails left by the Russian meteor as it passed over the city of Chelyabinsk in the Ural Mountains (image credit: AP Photo/Chelyabinsk.ru)

– Some of the surviving pieces of the Chelyabinsk bolide (meteor) fell to the ground. But the explosion also deposited hundreds of tons of dust up in the stratosphere, allowing a NASA satellite to make unprecedented measurements of how the material formed a thin but cohesive and persistent stratospheric dust belt. ⁶⁹²²⁾

About 3.5 hours after the initial explosion, the OMPS (Ozone Mapping Profiling Suite) instrument's Limb Profiler on the NASA-NOAA Suomi NPP spacecraft detected the plume high in the atmosphere at an altitude of about 40 km, quickly moving east at more than 300 km/h). The day after the explosion, the satellite detected the plume continuing its eastward flow in the jet and reaching the Aleutian Islands. Larger, heavier particles began to lose alti-

⁶⁹¹⁹⁾ "2013 Russian meteor event," Wikipedia, Feb. 15, 2013, URL: http://en.wikipedia.org/wiki/2013_Russian_meteor_event

⁶⁹²⁰⁾ Don Yeomans, Paul Chodas, "Additional Details on the Large Fireball Event over Russia on Feb. 15, 2013," Space Daily, March 4, 2013, URL: http://www.spacedaily.com/reports/Additional_Details_on_the_Large_Fireball_Event_over_Russia_on_Feb_15_2013_999.html

⁶⁹²¹⁾ "One-Kilo Meteorite Fragment Found," Space Daily, Feb. 26, 2013, URL: http://www.spacedaily.com/reports/One_Kilo_Meteorite_Fragment_Found_999.html

⁶⁹²²⁾ Kathryn Hansen, NASA's Earth Science News Team, "Around the World in Four Days: NASA Tracks Chelyabinsk Meteor Plume," NASA/GSFC, Aug. 14, 2013, URL: <http://www.nasa.gov/content/goddard/around-the-world-in-4-days-nasa-tracks-chelyabinsk-meteor-plume/#.UgyMs6zOIWL>

tude and speed, while their smaller, lighter counterparts stayed aloft and retained speed – consistent with wind speed variations at the different altitudes.

By Feb. 19, 2013, four days after the explosion, the faster, higher portion of the plume had snaked its way entirely around the Northern Hemisphere and back to Chelyabinsk. But the plume's evolution continued: At least three months later, a detectable belt of bolide dust persisted around the planet.

Scientists estimate that between 4000 to 6000 kg of meteorites fell to the ground. This amount included one fragment weighing approximately 650 kg. This fragment was recovered from Lake Chebarkul on Oct. 16, 2013 by professional divers guided by Ural Federal University researchers in Yekaterinburg, Russia.

Trajectory parameters: ⁶⁹²³⁾

- Length of luminous path: 272 km
- Observed height span: 95.1 – 12.6 km
- Slope: 18.5° at the beginning, 17° at the end
- Initial velocity: 19.03 ± 0.13 km/s
- Terminal velocity: 3.2 km/s
- Duration of the bolide: 16 seconds.

In March 2014, Russian media are reporting that scientists from Nizhny Novgorod have found natural magnesium–iron **nanocrystals** while studying the fragments of the meteor. This can give new information about the nature of nanomaterials and the conditions of their natural formation. The meteor's nanocrystals consist of ferropericase. This material can be found in magnesium, iron and oxygen. It's formed only in the upper layers of mantle under extremely high pressure and temperature. Moreover, the nanocrystals found in the meteor, have an ideal spherical form. This means that the meteor underwent high temperatures and immense pressure. ⁶⁹²⁴⁾

- **Tunguska Event:** On June 30, 1908, a large meteoroid or comet impacted in the Tunguska region of Russia (Siberia) with an enormously powerful explosion that occurred near the Podkamennaya Tunguska River in what is now Krasnoyarsk Krai, Russia. The explosion, having the epicenter (60.886°N, 101.894°E), is believed to have been caused by the air burst of a large meteoroid or comet fragment at an altitude of 5–10 km above the Earth's surface. Different studies have yielded widely varying estimates of the object's size, on the order of 100 m. It is the largest impact event on or near Earth in recorded history. Estimates of the energy of the blast range from 3 to as high as 30 megatons of TNT. The Tunguska explosion knocked down an estimated 80 million trees over an area covering 2,150 km². ⁶⁹²⁵⁾
 - A century later some still debate the cause and come up with different scenarios that could have caused the explosion, but the generally agreed upon theory is that on the morning of June 30, 1908, a large space rock, about 100 m across, entered the atmosphere of Siberia and then detonated in the sky. ⁶⁹²⁶⁾

⁶⁹²³⁾ Jiri Borovicka, "The Chelyabinsk event – what we know one year later," Proceedings of the 51st Session of Scientific & Technical Subcommittee of UNCOPUOS, Vienna, Austria, Feb. 11–22, 2014, URL: <http://www.unoosa.org/pdf/pres/stsc2014/tech-04E.pdf>

⁶⁹²⁴⁾ Milena Faustova, "Chelyabinsk meteor to help develop nanotechnology," Space Daily, March 11, 2014, URL: http://www.spacedaily.com/reports/Chelyabinsk_meteor_to_help_develop_nanotechnology_999.html

⁶⁹²⁵⁾ "Tunguska event," Wikipedia, URL: http://en.wikipedia.org/wiki/Tunguska_event

⁶⁹²⁶⁾ Tony Phillips, "The Tunguska Impact — 100 Years Later," NASA Science News, June 30, 2008, URL: http://science.nasa.gov/science-news/science-at-nasa/2008/30jun_tunguska/

- Near–Earth objects are asteroids or comets, meters to tens of kilometers in size, that orbit the Sun and whose orbits come close to that of Earth's. Of the more than 600 000 known asteroids in our Solar System, over 16 000 are classified as NEOs. ⁶⁹²⁷⁾
- On 30 June 1908, above the skies of Tunguska in Russia, such an object 30–40 m in diameter and travelling at approximately 100,000 km/hour penetrated Earth's atmosphere.
- It heated to approximately 10,000°C and exploded between six and ten km above the ground. The blast released the equivalent energy of 10–15 megatons of TNT, destroying 2200 km² of forest and leaving few traces of life.
- On 30 June, the United Nations observes International Asteroid Day, which aims to raise awareness about asteroids and the need to take action to protect Earth, humankind and future generations.
- Near–Earth objects could potentially hit our planet and, depending on their size, produce considerable damage. While the chance of a large object hitting Earth is very small, it would produce a great deal of destruction.



Figure 1593: Fallen trees at Tunguska, Imperial Russia, seen in 1929, 15 km from epicenter of aerial blast site, caused by explosion of a meteor in 1908 (Photo N. A. Setrukov, 1928)

Microgravity (μg) on the ISS: Gravity on Earth is abbreviated as 1g. The prefix "micro–" refers to one–millionth, so that microgravity implies 1/1,000,000 (or 10^{-6}) of Earth's gravity. Microgravity researchers take advantage of the fact that their experiments, along with everything else in the ISS (International Space Station), are free falling. While in orbit on the space station, these investigations do not experience the effects of gravity, such as buoy-

⁶⁹²⁷⁾ "Tunguska Devastation," ESA, 07 June 2018, URL: http://m.esa.int/spaceinimages/Images/2018/06/Tunguska_devastation

ancy, convection or sedimentation. These effects, which tend to cause fluids to move and mix in our 1g environment here on Earth, are greatly reduced in orbit.⁶⁹²⁸⁾

The precise value and fluctuations of the microgravity environment are important in interpreting the data from station investigations. There are accelerometer systems in orbit to measure the microgravity environment. Two of those systems are sponsored by NASA/GRC (Glenn Research Center) in Cleveland, OH: **SAMS** (Space Acceleration Measurement System) and **MAMS** (Microgravity Acceleration Measurement System).

MAMS measures low frequency, low magnitude vibrations or accelerations below 0.01 Hz. This is one vibration every 100 seconds, which is very slow. Typically, large massive structures vibrate slowly. These accelerations include the effects of aerodynamic drag that are typically smaller than $1 \mu\text{g}$. The nature of these accelerations is such that measurements can be made at one location and applied to any other location on the space station.

SAMS, on the other hand, deploys multiple accelerometers throughout the space station to measure higher frequency accelerations, between 0.01 to 300 Hz, which typically range from 10 to several thousand μg . These vibrations require measurements close to the point of origin and tend to come from equipment like fans and pumps or from crew activity such as exercise. In addition, SAMS measures transient vibrations, which are relatively brief and fairly strong.

These accelerations can be caused by crew movement pushing off bulkheads and landing, from vehicle thrusters to maintain attitude or reboost altitude, vehicle dockings and machinery start up. Such activities can produce peak measurements of more than ten-thousand μg 's.

SAMS also plays an important role in monitoring the space station's structural integrity. SAMS' measurements are analyzed to determine the exact nature of flexing and bending of important space station structures, its 'backbone,' to assess vehicle longevity. Recent analysis suggests that the space station will be sturdy and safe enough as a microgravity research platform until about the year 2028.

As a result of the measurements collected by SAMS and MAMS, researchers are able to monitor continuously the true nature of and small changes in the microgravity environment on the space station. Researchers at Glenn receive the data from these instruments as it streams down from station, displaying in near real-time on the Web. An archive of the data provides this information to sustaining engineering, scientific investigators and the microgravity community at-large.

⁶⁹²⁸⁾ "How Do We Know It's Really Microgravity?," Space Daily, June 13, 2013, URL: http://www.spacedaily.com/reports/How_Do_We_Know_Its_Really_Microgravity_999.html



Figure 1594: The SAMS tri-axial sensor measures acceleration in three directions, to obtain data aboard the ISS (image credit: NASA)

Microprocessor (early history). The history of microprocessors began in Nov. 1971 with the introduction of Intel's 4-bit 4004 microprocessor, a chip containing 2,300 PMOS (p-type Metal Oxide Semiconductor) transistors that is regarded the world's first microprocessor. The device contained all the arithmetic, logic, and control circuitry required to perform the functions of a computer's central processing unit (CPU). A microprocessor is built entirely of these logic circuits synchronized to each other – and combining the circuitry for both information storage and information processing. The general-purpose 4004 microprocessor, also referred to as MSC-4 (Microcomputer System 4-bit) computer, had a clock rate of 108 kHz and 640 Bytes of addressable memory.

- The Pioneer 10 spacecraft, an interplanetary probe of NASA/JPL (launch March 2, 1972), is considered to have introduced the first microprocessor into a spaceborne mission in history, the Intel 4004 with a 4-bit instruction set.
- In April 1972, Intel introduced the first 8-bit 8008 microprocessor. Its successor, the 8-bit 8080 CPU was released in April 1974 running at 2 MHz (at up to 500,000 instructions/s); it is generally considered to be the first truly usable microprocessor CPU design. It was implemented in NMOS (n-type Metal Oxide Semiconductor) technology. The 8080 chip contained 6,000 transistors, had a memory of 64 kByte, and supported up to 256 input/output (I/O) ports, accessed from programs via dedicated I/O instructions – each instruction taking an I/O port address as its operand. The 8080 represented Intel's fourth entry into the market. The competing Motorola 6800 microprocessor was released in August 1974. – The new microprocessors on the market started in fact a revolution in the computing history of the 1980s. The microprocessor technology has simply become the most prevalent implementation of the CPU, nearly completely replacing all other forms.
- In 1978, the 8080 microprocessor turned out to be the first microprocessor flown on an Earth observation spacecraft, namely the SEASAT mission of NASA/JPL (launch June 27, 1978).
- A seminal microprocessor in the world of spaceflight was RCA's RCA 1802, also referred to as CDP 1802, or in RCA's terms the COSMAC (Complementary Silicon Metal-oxide Conductor) microprocessor, introduced in 1976 which was used in NASA's Voyager space probes with launches in 1977. The CDP1802 was used because it could be run at very

low power, and because its production process (silicon on sapphire) ensured much better protection against cosmic radiation and electrostatic discharges than that of any other processor of the era. Thus, the CDP1802 is said to be the first radiation-hardened microprocessor. The Voyager-1 mission was launched Sept. 5, 1977 (Voyager-2 launch on Aug. 20, 1977).

Microwave radiation. This is electromagnetic radiation generally considered to be in the wavelength range from approximately 1 mm to 1 m (three orders of magnitude). Radiometry addresses the domain of passive measurement of the natural thermally caused electromagnetic radiation of matter at a physical temperature above 0 K. In the case of MW (Microwave) and MMW (Millimeter Wave) Earth observation, significant contrasts can be observed between reflective and absorbing materials due to the impact of reflected sky radiation of cosmic origin. The incident radiation power measured by a radiometer system is usually expressed in an apparent temperature, the so-called brightness temperature. For Earth observation an approximate range from 3 K to more than 300 K can be observed. In the MW and MMW region the spatial two-dimensional brightness temperature distribution can be used as a daytime and almost weather independent indicator for many different physical phenomena.

In microwave radiometry polarization is often used as a discriminant parameter, because microwave antennas are easily built with a single polarization direction. – (On the other hand, most optical sensors are relatively independent of polarization; a special effort must be made to polarize the signal prior to detection). – The largest portion of the microwave region is also the ‘radar’ region, hence both terms are used interchangeably (this also applies to the microwave instruments), see also Q.8.2 and Q.8.1.

Microwaves form the only portion of the electromagnetic spectrum that allows truly quantitative estimates of **soil moisture** using physically based models. Moreover, microwave remote sensing has the following important advantages over other portions of the spectrum:

- Microwave radiation penetrates clouds and, therefore, forms the basis for an all-weather observation tool
- Low-frequency microwaves partially penetrate vegetation and, therefore, allows soil moisture estimation from vegetated areas
- Low-frequency microwaves partially penetrate the soil surface and, therefore, emitted signatures contain information over the soil penetrated depth
- High-frequency microwaves are partially absorbed by vegetation and, therefore, emitted signatures contain information on vegetation properties
- Microwave radiation is independent of solar radiation and can therefore be used during both nighttime and daytime hours.

Microwave rainfall monitoring. Microwave radiation with wavelengths in the order of 1mm to 3 cm results in a strong interaction between the raindrops and the radiation (the drop size is comparable to the wavelength). Passive microwave data is helpful in locating the leading and trailing edges of rain areas (extent), however, the actual measurement of rainfall and rain rates provides unsatisfactory results. So far passive microwave systems function promisingly over sea surfaces but not satisfactorily over land surfaces. The general consensus is that a passive (multichannel and multipolarized radiometer)/active (radar) instrument complement can provide a better characterization of rain systems.

Radar measurement of rainfall is based on Rayleigh scattering caused by the interaction of rain and the radar signals. The PR (Precipitation Radar) instrument on TRMM with a transmission frequency of 14 GHz (2.15 cm wavelength) is expected to improve on the problem of rainfall measurement.

Microwave signal penetration. Most natural terrain materials, with the exception of water, are partially transparent to microwave frequencies. The energy of a (radar) wave incident

upon a terrain surface is partially scattered back into the atmosphere; the remainder is transmitted across the boundary into the terrain medium. – The most important parameters governing the depth to which microwaves can penetrate natural materials such as soil, snow, or vegetation are the wavelength, the moisture content of the material (soil), and the shape and sizes of the scattering elements (such as the leaves in a vegetation canopy, or ice crystals on a snow surface). Radar observations in L–band (2–1 GHz) and P–band (1.0 – 0.3 GHz) frequencies are providing first results in penetration measurements, in particular with regard to soil moisture content and canopy penetration. – Note: The microwave permittivity of liquid water (dielectric constant of about 80) is an order of magnitude higher than that of any natural dry material (dielectric constant of <4).⁶⁹²⁹⁾

Millimeter–Wave (MMW) region. Refers to the spectral region from 1 mm (300 GHz) to 10 mm wavelength (30 MHz). The MMW region is part of the microwave region of the spectrum which extends conventionally from 1mm to 1 m wavelength. The MMW region is in particular of interest to radiometry (passive sensing) applications. Millimeter waves are able to penetrate many types of inclement weather, as well as opaque solids, and offers a lot of contrast. The emissivity of objects in this region is about 10 times higher than that in the infrared region.

Submillimeter–wave (SMMW) region. Refers to the spectral region from 0.1 mm (3000 GHz or 3 THz) wavelength to 1 mm (300 GHz) wavelength. The SMMW is also being considered as part of the microwave region (as well as of the optical region). SMMW observations are of particular interest to atmospheric science. Submillimeter–wave limb sounding has some advantages compared with limb sounding in other frequency ranges. In the UV and VIS region only daytime measurements are possible, while in the infrared region some important species like ClO and HCl are not detectable.

Microwave total–power observation. An observation/calibration scheme referred to as “total–power method” which compares in the microwave region the atmospheric signal to the cold and hot loads.

MKID (Microwave Kinetic Inductance Detector): MKIDs, are non–equilibrium superconducting detectors made out of high quality factor superconducting microwave resonant circuits. Their primary advantage over other low temperature detector technologies is their built–in frequency domain multiplexing at GHz frequencies, allowing thousands of detectors to be read out through a single transmission line.

Modeling. An investigative technique that uses a mathematical or physical representation of a system or theory that accounts for all or some of its known properties. Models are often used to test the effects of changes of system components on the overall performance of the system.

Modulation. A process of manipulating the characteristics (usually frequency or amplitude) of a carrier in relation to another wave or signal.

Modulation Transfer Function (MTF).⁶⁹³⁰⁾ A function measuring the reduction in contrast from object to image (actually from each pixel), that is, the ratio of image–to–object modulation for sinusoids of varying spatial frequencies. The reason: any optical system reduces the contrast in the image compared to the contrast of the objects imaged; this is expressed as MTF. Thus, the MTF provides the response of an optical sensor as a function of object scene contrast and spatial frequency. MTF is also a measure of how accurately the actual radiance from a pixel (IFOV) is measured (a lower MTF indicates contributions from other pixels to the pixel of observation). The higher the MTF the greater the resolving power of that sys-

6929) The penetration depth of microwaves decreases with increasing frequency. The atmosphere produces frequency–dependent distortions which set an upper frequency limit due to attenuation. This limit is about 90 GHz for airborne radars and about 15 GHz for spaceborne radars.

6930) G. Joseph, “How well do we understand Earth observation electro–optical sensor parameters?” ISPRS Journal of Photogrammetry & Remote Sensing, Vol. 55, 2000, pp. 9–12

tem. A radiometrically accurate IFOV is one for which $MTF > 0.95$. Note: The value of MTF is not only reduced by the aberrations within the optical system, but also the Earth's atmosphere. Haze, turbulence and differential refraction will each contribute to a reduction in the total performance of the telescope.

Note: EIFOV (Effective Instantaneous Field of View) is defined as the resolution corresponding to a spatial frequency (ground resolution) for which the system MTF is 50%.

Moire Interferometry. A method to determine 3–D profile information of an object or scene, using interference patterns. Two identical gratings of known pitch are used. The first create a shadow of parallel lines of light projected on the object. The second is placed in the imaging train, then superimposed on the shadow cast by the first grating, forming a moire fringe pattern. Varying the gap between the lines changes the sensitivity.

Mosaic. An assemblage of overlapping airborne or spaceborne photographs or images whose edges have been matched to form a continuous pictorial representation of a portion of the Earth's surface.

Multilook technique. A technique of averaging a number of independent samples per pixel. applied to radar in order to reduce speckle.

Multiple access techniques. There are three basic multiplexing schemes that allow a number of simultaneous transmissions over a single circuit. See also **CDMA**, **FDMA**, and **TDMA** in the glossary text.

- **Code Division Multiple Access (CDMA).** Refers to an access scheme which employs spread–spectrum modulations and orthogonal codes to share a communication link among its users.
- **Frequency Division Multiple Access (FDMA).** A process that shares a spectrum of frequencies among many users by assigning to each a subset of frequencies in which to transmit signals.
- **Time Division Multiple Access (TDMA).** A process that shares the time domain of a single carrier among many users by assigning to each time intervals in which to transmit signal bursts.

Multipath (GPS multipath).⁶⁹³¹ The term multipath is derived from the fact that a signal transmitted from a GPS satellite can follow a 'multiple' number of propagation 'paths' to the receiving antenna. This is possible because the signal can be reflected back to the antenna off surrounding objects, including the Earth's surface (land and/or ocean). Some characteristics of the multipath signal are: a) a multipath signal arrives always at a later time than the direct–path signal, b) a multipath signal is normally weaker than the direct–path signal due to the reflection loss, c) if the delay of the multipath is less than two PRN code chip lengths, the internally generated receiver signal will partially correlate with it. If the delay is > 2 chips, the correlation power will be negligible.

Multiplet. A spectrum line having several components.

Multispectral. In remote sensing the term implies two or more (generally < 10) broad spectral bands in which a sensor detects radiation (see also **Hyperspectral**). The bands of multispectral instruments are generally tailored to suit a specific application (the bands may be less than optimal or even completely unsuitable for other applications). The multispectral concept implies image analysis based on spectral characteristics. Note: The MSS (Multispectral Scanner System) sensor on Landsat–1 was the first spaceborne multispectral instrument with four spectral bands in VNIR.

⁶⁹³¹) B. Townsend, J. Wiebe, A. Jakab, M. Clayton, T. Murfin, "Analysis of the Multipath Meter Performance in Environments With Multiple Interferers," ION GPS 2000, Salt Lake City, UT, Sept. 19–22, 2000, pp. 480–488

Nadir. Direction toward the center of the Earth. Opposite of zenith.

NEOs (Near Earth Objects): NEOs are asteroids or comets with sizes ranging from meters to tens of kilometers whose orbits come close to ours, meaning they could hit our planet. The international effort to find, confirm and catalog the multitude of asteroids that pose a threat to our planet has reached a milestone in 2016: 15 000 discovered – with many more to go. ⁶⁹³²⁾

The discovered NEOs are part of a much larger population of more than 700,000 known asteroids in our Solar System. “The rate of discovery has been high in the past few years, and teams worldwide have been discovering on average 30 new ones per week,” says Ettore Peruzzi, manager of the NEO Coordination Center at ESA’s center near Rome, Italy. “A few decades back, 30 were found in a typical year, so international efforts are starting to pay off. We believe that 90% of objects larger than 1000 m have been discovered, but – even with the recent milestone – we’ve only found just 10% of the 100 m NEOs and less than 1% of the 40 m ones.” Today, the two main discovery efforts are in the US: the Catalina Sky Survey in Arizona, and the Pan–STARRS (Panoramic Survey Telescope & Rapid Response System) project in Hawaii, jointly accounting for about 90% of the new bodies found.

NEOs could potentially hit our planet and, depending on their size, produce considerable damage. While the chance of a large object hitting Earth is very small, it would produce a great deal of destruction. NEOs thus merit active detection and tracking efforts. ⁶⁹³³⁾

An example of a NEO is [25143 Itokawa](#), an object about 300 m in diameter that was visited by the Japanese spacecraft Hayabusa in 2005.

The ASTRO–F / AKARI infrared astronomy satellite of JAXA observed asteroid Itokawa in July 2007 with its Infrared Camera. The data will be used to refine estimates of sizes of potentially hazardous asteroids in the future. As AKARI observed **Itokawa** on 26 July, it was in the constellation of Scorpius, and was about 19 magnitudes bright in visible light. The asteroid and Earth were closest to each other, at a distance of about 42 million km (for comparison, Earth is 150 million km from the Sun). Given how close it was, Itokawa moved a significant distance on the sky over the short observing time. ⁶⁹³⁴⁾

Using observational data of asteroids such as Itokawa in combination with data from the explorer, models that estimate asteroid sizes can be made more accurate. This is especially useful for estimating the size of potentially hazardous asteroids which may be discovered in the future.

Before Hayabusa arrived at Itokawa, many observations to determine the asteroid’s approximate size had already been attempted. Among the many different methods of measurement, the most accurate estimate was achieved by mid–infrared observations.

With AKARI, it was possible to observe Itokawa at several different wavelengths in the mid–infrared range, obtaining a much more comprehensive set of data. This data is very important, not only for the study of the asteroid’s infrared properties, but also for use as a template and source of comparison with other asteroids, to improve the estimates of their sizes.

6932) “15,000 space rocks and counting,” ESA, Oct. 26, 2016, URL: http://m.esa.int/Our_Activities/Operations/Space_Situational_Awareness/15_000_space_rocks_and_counting

6933) “Near–Earth Objects – NEO Segment,” ESA, URL: http://m.esa.int/Our_Activities/Operations/Space_Situational_Awareness/Near–Earth_Objects_–_NEO_Segment

6934) “AKARI’s observations of asteroid Itokawa,” ESA, 23 Aug.2007, URL: http://m.esa.int/Our_Activities/Space_Science/AKARI_s_observations_of_asteroid_Itokawa

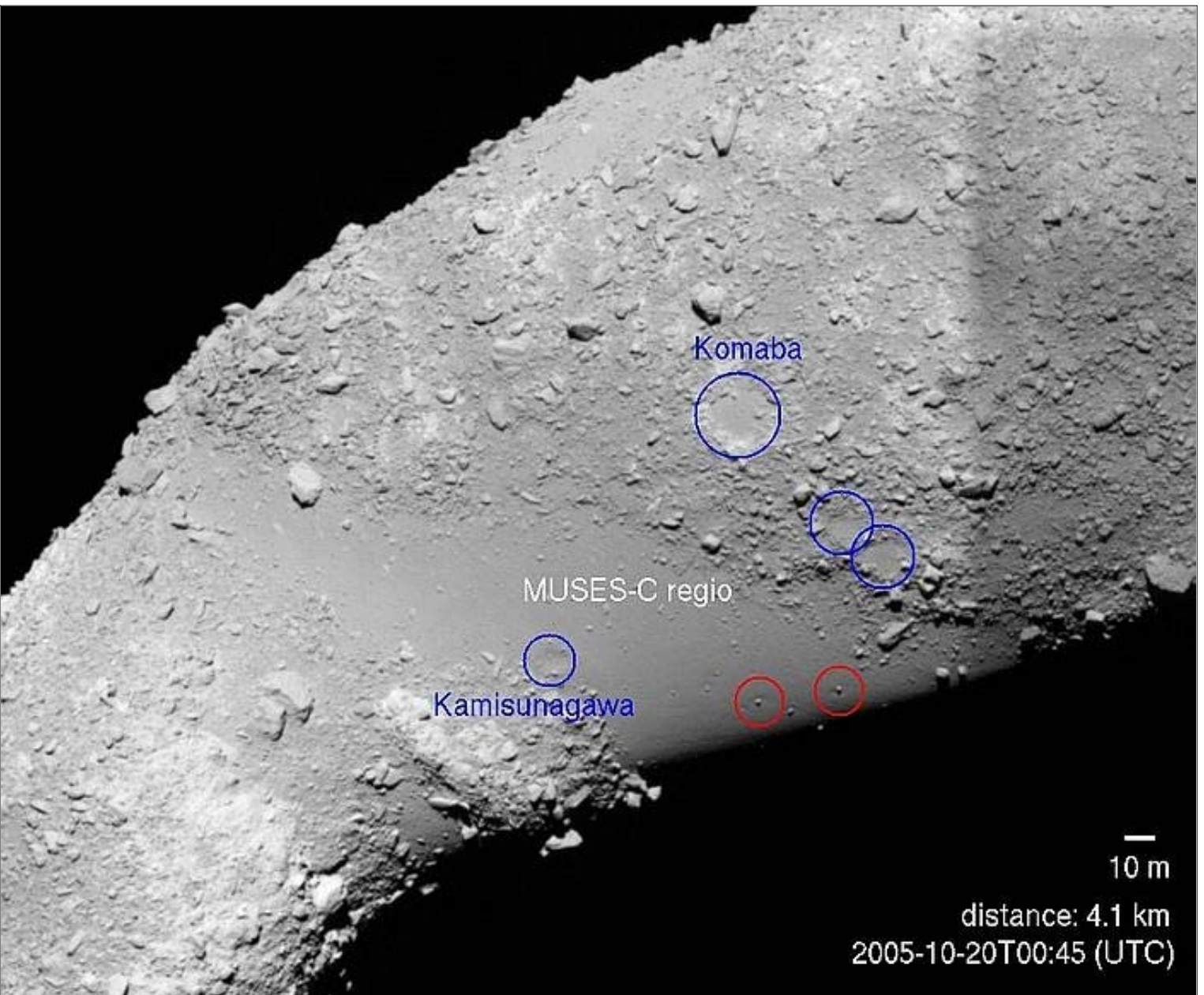


Figure 1595: The asteroid was discovered in 1998 by the LINEAR project, and given the provisional designation 1998 SF36. In 2000, it was selected as the target of Japan's Hayabusa mission. Soon thereafter, it was officially named after Hideo Itokawa, a Japanese rocket scientist (image credit: JAXA)

- The story of asteroid Itokawa continues. **In August 2018, a Japanese research group, including scientists from Osaka University, closely examined particles collected from the asteroid Itokawa by the spacecraft Hayabusa, finding that the parent body of Itokawa was formed about 4.6 billion years ago when the solar system was born and that it was destroyed by a collision with another asteroid about 1.5 billion years ago. Their research results were published in Scientific Reports.** ⁶⁹³⁵⁾ ⁶⁹³⁶⁾

- Focusing on a few micrometers of phosphate minerals, which are rarely found in Itokawa particles, the scientists performed precise isotope analyses of uranium (U) and

6935) "Particles give absolute age of asteroid Itokawa," Osaka University, 8 August 2018, URL: http://resou.osaka-u.ac.jp/en/research/2018/20180808_1

6936) K. Terada, Y. Sano, N. Takahata, A. Ishida, A. Tsuchiyama, T. Nakamura, T. Noguchi, Y. Karouji, M. Uesugi, T. Yada, M. Nakabayashi, K. Fukuda, H. Nagahara." Thermal and impact histories of 25143 Itokawa recorded in Hayabusa particles," Scientific Reports, 2018; 8 (1) DOI: 10.1038/s41598-018-30192-4

lead (Pb) in Itokawa particles of about $50\ \mu\text{m}$ in diameter using SIMS (Secondary Ion Mass Spectrometry).

- Lead author Kentaro Terada says, “By combining two U decay series, ^{238}U – ^{206}Pb (with a half–life of 4.47 billion years) and ^{235}U – ^{207}Pb (with a half–life of 700 million years), using four Itokawa particles, we clarified that phosphate minerals crystallized during a thermal metamorphism age (4.64 ± 0.18 billion years ago) of Itokawa’s parent body, experiencing shock metamorphism due to a catastrophic impact event by another body 1.51 ± 0.85 billion years ago.”
- It has been reported that the mineralogy and geochemistry of the Itokawa particles resemble those of LL (LL stands for Low (total) iron, Low metal) chondrites, which frequently fall to the Earth.
- However, the shock ages of Itokawa particles obtained from this study (1.5 billion years ago) are different from previously reported shock ages of shocked LL chondrites (4.2 billion years ago). This shows that the asteroid Itokawa had a time evolution different from that of the parent body of LL chondrites.
- The results of this study established constraints on the timescale of the first samples collected from the asteroid, providing concrete figures (absolute age) to the evolution of the NEAs whose orbits are well known. This will lead to the elucidation of the origins and histories of asteroids.

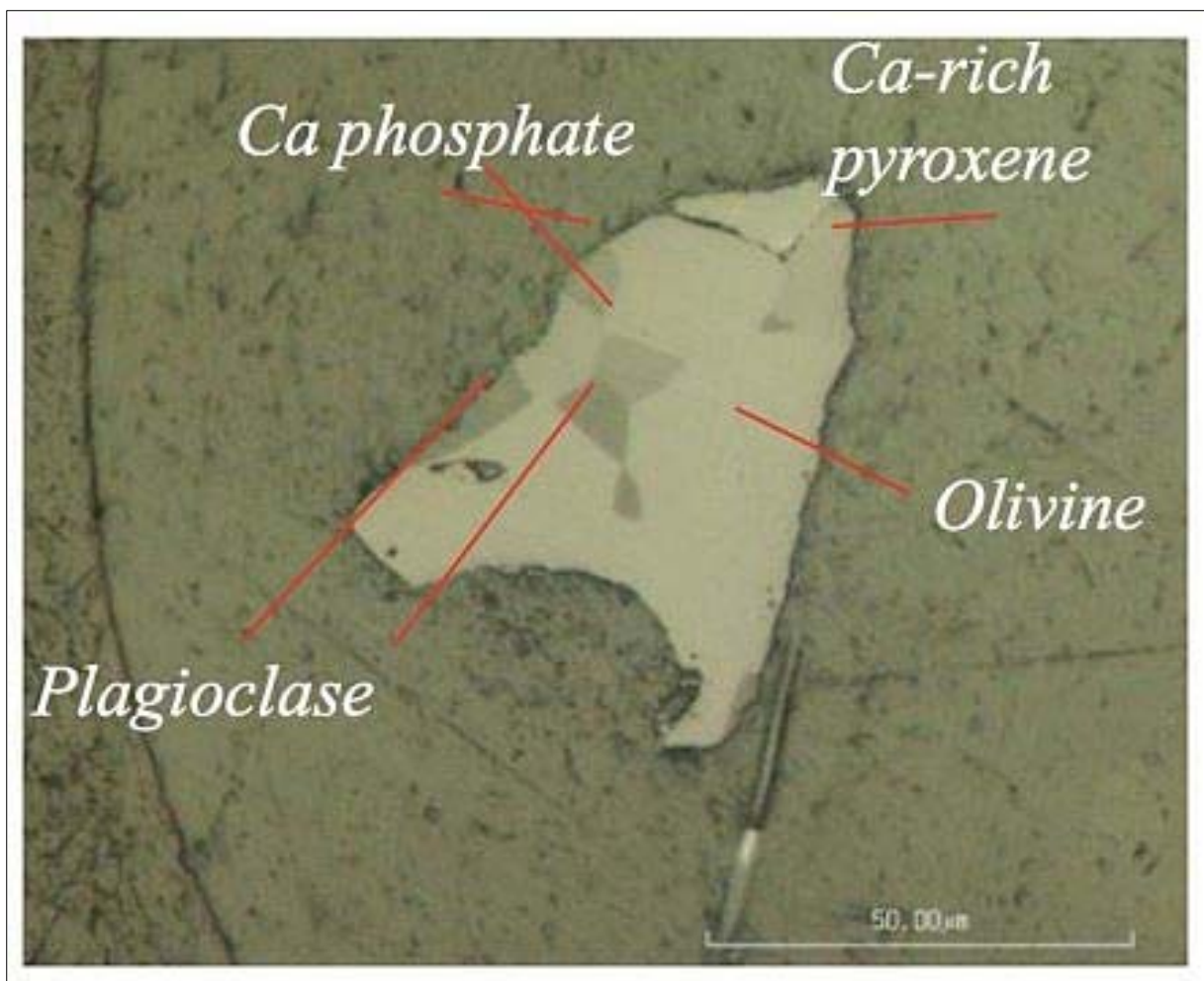


Figure 1596: This is the cross section area of the particle collected from the asteroid Itokawa using Hayabusa spacecraft (image credit: Osaka University)

Nilas. Thin and elastic ice sheets of a rather dull surface and up to a thickness of about 10 cm. Nilas form in quiet sea water and bend easily in swells. Transverse pressure causes nilas

to pile up. **Leads** may be frozen over by nilas; but nilas are not bound to be present in leads; they may also occur outside of leads.

Noctilucent (night–shining) Clouds: Refers to a cloud–like phenomenon of a pervasive polar cloud layer called “polar mesospheric clouds” in the upper atmosphere, visible in a deep twilight. They are most commonly observed in the late spring and summer months at latitudes between 50° and 70° north and south of the equator. They are thin, wavy ice clouds that form at very high altitudes (76 to 85 km) above Earth’s surface and reflect sunlight long after the sun has dropped below the horizon. The noctilucent clouds form when there is sufficient water vapor at these high altitudes to freeze into ice crystals. ⁶⁹³⁷⁾

While the exact cause for the formation of polar mesospheric clouds is still debated—dust from meteors, global warming, and rocket exhaust have all been suggested as contributors—recent research suggests that changes in atmospheric gas composition or temperature has caused the clouds to become brighter over time.

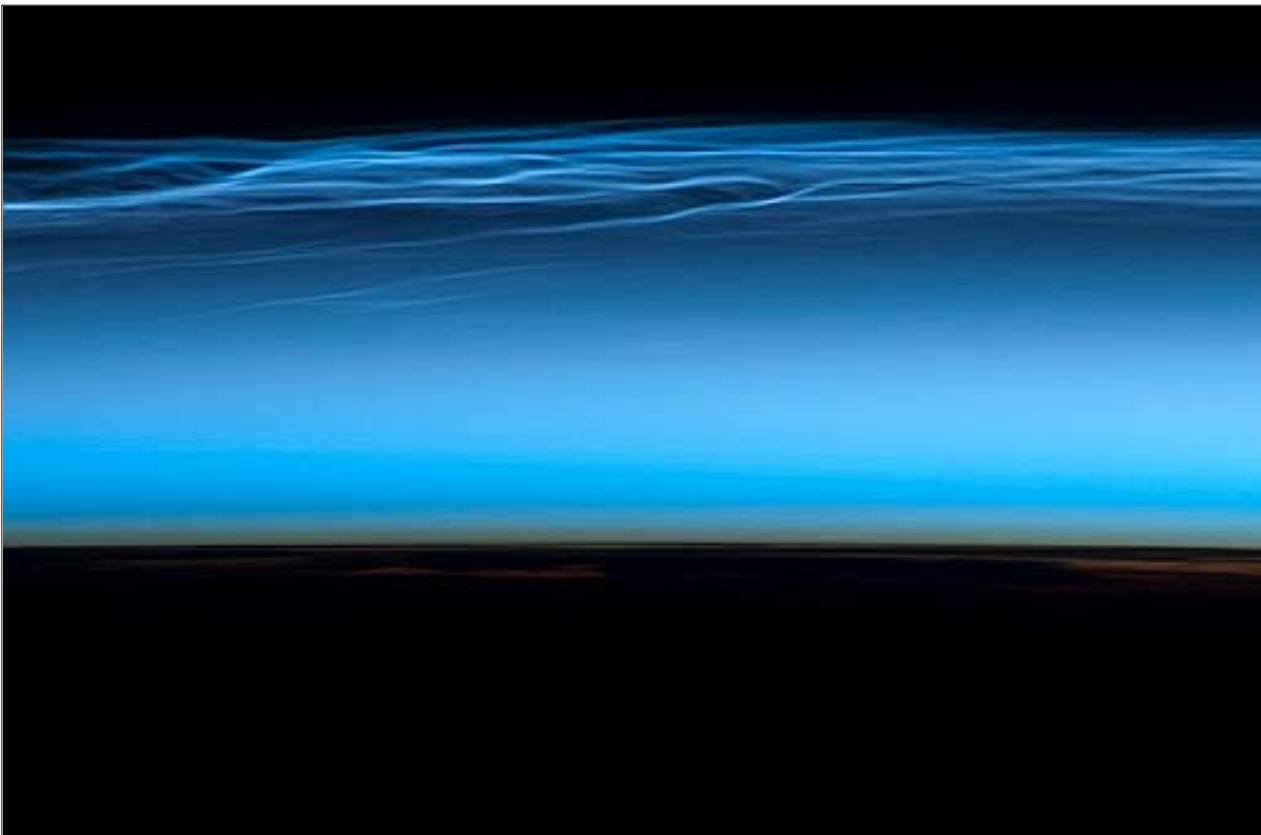


Figure 1597: Astronaut photograph ISS031–E–116058 of noctilucent clouds, acquired on June 13, 2012, from the ISS with a Nikon D2Xs digital camera (image credit: NASA/JSC) ⁶⁹³⁸⁾

Noise. Any unwanted or contaminating signal competing with the desired signal. In a SAR instrument, two common kinds of noise are additive, receiver noise and signal–dependent noise, usually additive or multiplicative. The relative amount of additive noise is described by the signal–to–noise ratio (SNR). Signal–dependent noises, such as azimuth ambiguities or quantization noise, arise from system imperfections, and are dependent on the strength of the signal itself.

Noise–Equivalent–Equivalent–Width (NEEW) (sometimes shortened to ‘noise–equivalent–width’). A spectral resolution defining the smallest line area (in cm^{-1}) that can be measured, or the equivalent area of the average noise bump.

⁶⁹³⁷⁾ http://en.wikipedia.org/wiki/Noctilucent_cloud

⁶⁹³⁸⁾ <http://earthobservatory.nasa.gov/IOTD/view.php?id=78346>

Noise–Equivalent Flux Density (NEFD), sometimes also referred to as ‘noise–equivalent irradiance.’ Defined as the in–band entrance aperture irradiance on one pixel, from a point source, that equals the sensor rms noise (units are W/cm^2). NEFD is related to a more familiar quantity, the Noise–Equivalent Radiance (NER), by the equation: $NEFD = NER \times \text{pixel subtends (in steradians)}$. NEFD can also be defined as the noise–equivalent power (NEP) per unit aperture area: $NEFD = NEP/A$.

Noise–Equivalent Radiance (NER). Defined as the in–band entrance aperture radiance ($W/cm^2/sr$) equal to the sensor rms noise. NER is the preferred figure of merit for an extended (pixel–filling) source. It is also defined as the noise–equivalent power (NEP) per unit aperture area, per pixel subtense ($NER = NEP/A/\Omega$).

Noise–Equivalent Spectral Radiance (NESR). Defined as the radiance ($W\ cm^{-2}\ sr^{-1}\ cm^{+1}$) density that corresponds to the rms value of the spectral noise of a calibrated spectrum (or: the radiance change corresponding to $SNR=1$). $NESR = NEP / (\mu \times \tau \times E \times (t)^{1/2} \times \Delta\sigma)$, with NEP = Noise Equivalent Power of the detector, μ = modulation efficiency, τ = optical efficiency, E = Etendue, t = scan time (1 instance), and $\Delta\sigma$ = spectral resolution.

Noise Equivalent Temperature Difference (NETD) also referred to as NEDT (Noise Equivalent Differential Temperature). The noise rating of an IR FPA detector specifies the amount of radiation required to produce an output signal equal to the detectors own noise (due to inner component heat). Thus, it specifies the minimum detectable temperature difference. In general detector cooling is required to limit the detector’s own noise and to improve the NETD.

Noise figure. Ratio of total output noise power of a system to that part of the output noise power due to the signal source.

Nonimaging sensors. Instruments which measure directly such quantities as radiant flux, irradiance, and radiance, which describe the intensity of a radiation field or the optical properties of a surface or a region of space. The sensors are nonimaging in the sense that they do not produce an image (a picture), but rather, integrate over time, space, and wavelength to produce a spectral curve, or a set of numbers that characterize the electromagnetic radiation. Typical measurement products are profiles, such as flux profiles, temperature profiles, moisture profiles, etc. Typical nonimaging instruments are: radar altimeters, sounders, scatterometers, spectroradiometers, radiometers, (note: there are also imaging radiometers which use scanning techniques, and imaging spectroradiometers using discrete filter–wheel systems), lidars, etc.

Nowcasting. The term is used in meteorology and refers to the development of atmospheric features on time scales between 0 and 3 hours over regional and local areas. Nowcasting is closely linked to very short–range–forecasting which covers developments over the time scale of 3 to 12 hours over regional areas.⁶⁹³⁹⁾ A typical example of an application of nowcasting is severe weather incidents, where small–scale features undergo rapid development. Nowcasting requires the (almost) continuous monitoring of the area(s) of interest. Furthermore, as many of the features to be observed are fairly small, quite high spatial resolutions are needed.

Nyquist sampling rate (Henry Nyquist, a US physicist and a pioneer in the field of communication theory, was borne in 1889 in Sweden).⁶⁹⁴⁰⁾ – Refers to a sampling rate above which a band–limited signal can be reconstructed from its sample value. If a signal $s(t)$ contains no frequency components at or above f_N Hz [$s(t)$ is then said to be band–limited to f_N Hz], then $s(t)$ can be completely reconstructed from its sample values, provided the samples are taken at a rate equal to or in excess of $f_S = 2 f_N$ samples/s. **This condition is known as the Nyquist or Shannon sampling theorem;** f_S is referred to as the Nyquist sample frequency,

6939) “Meteosat Second Generation Programme Proposal,” ESA/PB–EO (92), 57, 9 November 1992, p. 14

6940) F. J. Taylor, “Digital Signal Processing,” Encyclopedia of Physical Science and Technology, Academic Press, 1987, Vol. 12. p. 600

and f_N is sometimes called the Nyquist frequency. The Nyquist theorem essentially states that the sampling rate must be twice that of the highest frequency to be represented. For example, in a digital camera with 5 μm pixel spacing, $f_s = 200$ pixel/mm, and $f_N = 100$ line pairs/mm.

Observational reference frames and models:

- **Lagrangian experiments** (Joseph Louis Lagrange, 1736–1813, French mathematician and physicist). Refer to a physical system that changes as time goes on from one configuration to another as it is progressing along a particular evolutionary path (path with the smallest result). In this concept observer and observed object have zero velocity relative to each other (Lagrangian coordinates are also referred to as ‘material coordinates;’ they do not vary with time). The strategy is to observe a reference volume (a cell of air) of interest as it moves through space. All measuring devices move along with the reference object. The concept is generally very complex with respect to instrumentation. Drifting buoys in the ocean or constant–pressure balloons in the atmosphere are Lagrangian–type experiments of relatively small complexity.
- **Eulerian experiments** (Leonard Euler, 1707–1783). In Eulerian coordinates the properties of a fluid are assigned to points in space at a given time, without attempt to identify the individual fluid cells from one time to the next. The observer moves relative to the observed object. Example: observation of air masses. The vast majority of experiments, particularly in meteorology, are of the Eulerian type; a sequence of synoptic charts is a Eulerian data representation.
- **Transect experiments.** The observer takes snapshot measurements by transecting a large reference volume into different directions. Example: an aircraft or a ship observes many different small–scale air masses as it moves through them.

Occultation. Distortion or interruption of a direct observation path between the observer (sensor) and a target by an intervening medium (such as an atmosphere or a celestial body). The occultation technique may for instance be used to study the Earth’s atmosphere (or planetary atmospheres) by remote sensing (in a limb–viewing configuration). The atmosphere causes signal propagation delay and bending [between a transmitter (a GPS satellite) and a receiver (a GPS receiver on a LEO satellite)] due to the variation in the index of refraction in different shells of the atmosphere. – In the conventional sense, occultation refers to light path obstruction by an astronomical body, such as a star, by another astronomical body, as seen from Earth. In this context, a solar eclipse is the occultation of the sun by the moon.

Ocean Acoustic Tomography (OAT):⁶⁹⁴¹⁾ OAT is a technique permitting the study of average temperatures over large regions of the ocean. Principle: Sound travels faster in warm water than in cold water. By measuring the travel time of sound over a known path, the sound speed and thus temperature can be determined. Sound also travels faster with a current than against. By measuring the reciprocal travel times in each direction along a path, the absolute water velocity can be determined. In ocean acoustic tomography, data from a multitude of such paths crossing at many different angles are used to reconstruct the sound speed (temperature) and velocity fields. – Since the technique integrates temperature variations over a large region, the smaller scale turbulent and internal–wave features that usually dominate point measurements are averaged out; this permits to determine the large–scale dynamics.

Ocean color. A shorthand term for a specific set of measurements from airborne or spaceborne instruments used to determine the radiance backscattered from water and across the

6941) B. M. Howe, B. D. Dushaw, W. H. Munk, P. F. Worcester, “Monitoring the Ocean Acoustically: A Review and Strategy for the Future,” 82nd Annual Meeting of AMS, Sixth Symposium on Integrated Observing Systems, Orlando, FLA, Jan. 13–17, 2002

air–sea interface at some or many spectral bands. A more formal name for ocean color is ocean spectral reflectance (R) or water–leaving spectral radiance (L_w).

The color of the ocean reveals information on the presence and concentration of phytoplankton, sediments, and dissolved organic chemicals. By studying the color of the light scattered from the oceans, optical sensors can quantify the amount of chlorophyll and other constituents in the various regions of the ocean. – Ocean color gives a quantitative measure of the spectral radiance of light reflected from beneath the ocean surface. Since phytoplankton dominates the optical characteristics of most ocean waters, it permits the estimation of marine plant biomass, ocean optical properties, and marine photosynthesis (primary production), see also ‘chlorophyll.’

Ocean mixing. Processes that involve rates of advection, upwelling/downwelling, and eddy diffusion and that determine, for example, how rapidly excess atmospheric carbon dioxide can be taken up by the oceans.

Oceans of the world and climate. The oceans play a decisive role in the evolution of the climate. Through irradiation of the sun and exchanges with the atmosphere, they receive considerable quantities of heat, in particular at the intertropical latitudes, which they store due to their high thermal capacity, and which the ocean currents redistribute from the equatorial regions to the polar regions. – Current estimates account for 30–50% of the meridian transport which makes the climate of the middle latitudes more hospitable. Fluctuations in the circulation and elevation of the average sea level, under the combined effect of thermal expansion and the melting of the icepack, are indicators of climatic anomalies. – Thus, the world’s oceans represent a major regulating factor of the climatic system. Their circulation and evolution must be understood (via satellite altimetry or other means of observation) to account for the climate variability. Some figures of the oceans illustrate the importance of the oceans to our environment.

- About 70% of the Earth’s surface are covered with oceans, this amounts to a total area of 360×10^6 (million) km^2 , the total ocean volume is estimated to be 1.46×10^9 (billion) km^3 ; hence, the total mass is about 1.46×10^{18} metric tons.
- The average depth of the oceans is about 3800 m
- The mass of the oceans is about 300 times larger than the mass of the atmosphere; the heat storage capacity of the oceans is 1200 times the heat capacity of the atmosphere; the oceans provide 70 times the carbon storage capacity of the atmosphere. See also “altimetry” and “hydrosphere” in the glossary.

In addition to the normal ocean–atmosphere heat exchanges, the winds blowing on the sea surface, contribute to the productions of surface marine currents. These currents travel much more slowly than the winds; however, these ocean currents can store a large quantity of heat. This property enables the ocean to stabilize the Earth’s temperature. An example of such an ocean current is the Gulf Stream which forms in the west Atlantic seaboard (mainly in the Gulf of Mexico) and travels in the direction of northern Europe.

Ocean surface skin layer (also referred to as SSST (Skin Sea Surface Temperature – see also SST). A number of measurements have demonstrated the existence of a skin layer at the ocean surface. This skin layer is the molecular boundary between a turbulent ocean and a turbulent atmosphere. The molecular layer is necessary for the transfer of heat, momentum and other properties, between the ocean and the atmosphere. The thermodynamics of this layer also determines the flux of gases such as carbon dioxide between the sea and the atmosphere. ⁶⁹⁴²⁾

Omega. A long–range, worldwide, all weather, day and night radionavigation system operating in the VLF (Very Low Frequency) band of the radio spectrum. The Omega network

⁶⁹⁴²⁾ W. J. Emery, C. J. Donlon, G. A. Wick, “A Comprehensive Program to Validate Infrared Satellite Sea Surface Temperature Measurements,” Proceedings of IGARSS/IEEE, Sydney, Australia, July 9–13, 2001

consists of eight atomic–clock–controlled transmitters transmitting sequentially on assigned frequencies between 10.2 and 13.6 kHz. The Omega network transmitters are located in Argentina, Australia, Japan, Liberia, Norway, Reunion, and USA (Hawaii and North Dakota). Users of Omega are commercial airlines, ships, land vehicles, meteorology (tracking of balloons), etc. Omega, like LORAN, uses phase differences of continuous–wave radio signals. The receiver of a user synchronizes to the transmitter frequency and measures the phase relationship of the receiver’s location. Two or more ‘line–of–position’ measurements define the receiver location. Omega (of World War II vintage, developed by the USA) provides positioning within 2 to 4 nautical miles at a 95% confidence level with 95% availability. – The USA terminated permanently its Omega operations on Sept. 30, 1997.

Open Systems Interconnect (OSI) of communications. In the OSI model, there are seven distinct layers. The layers are:

- 1) Physical: raw bits, coding (wire, fiber, RF)
- 2) Link: Frames (HDLC, FDDI, ATM, ethernet)
- 3) Network: end–to–end addressed datagrams (IP)
- 4) Transport: multiplexed packets (TCP, UDP)
- 5) Session: login, authentication
- 6) Presentation: formatting, translation
- 7) Application: user data

Operational sensor. In Earth observation an instrument is said to be “operational” if the following services are provided: continuity of observations, timeliness of data delivery to the customer, and several usable data products. A number of environmental/meteorological missions, like NOAA/POES and GOES, the METEOSAT series, etc., with their major instruments (AVHRR, etc.) and services, are considered “operational.” Routine service provision and regular use of the data by a user community are key ingredients for operability.

Optical depth. Refers to the negative logarithm of the extinction $[\ln I/I_0]$, where I is the radiation intensity at the back plane of the absorbing medium, and I_0 the incident intensity. The optical depth is the product of the extinction coefficient, the density of the medium, and the length of the transmitted medium layer (Lambert Beer Law).

On–orbit electric propulsion systems. (see chapter Q.12)

Optical spectrum. Refers to electromagnetic radiation of frequency (or wavelength) that can be focused, dispersed, and detected using optical components such as lenses, mirrors, and gratings. This includes more than the narrow visible region; in general terminology the optical spectrum extends from 0.01 to 1000 μm (UV to FIR inclusive).

Optoelectronics.⁶⁹⁴³ The term is a contraction of ‘optical electronics’ and refers to the photon effects (interaction/conversion, transmission) with a medium and vice versa. Optoelectronics or photonics refers to the field that combines both optics and electronics into a single device, component, or subsystem. Optoelectronics is one of the foremost research fields affecting many areas of solid–state computer technology [microprocessors, data storage, communication (photon guidance between a source and a detector, optical fibers for signal transmission in optical communication, lasers), visual display methods using LEDs (Light Emitting Diode) and LCDs (Liquid Crystal Display)], energy detection and conversion [photon conversion into electrical energy (photodetection, photovoltaics), etc.]. Optoelectronics has also a wide field of applications in imaging sensor design (e.g., vidicons, CCDs,

6943) Special issue on Optoelectronics Technology, Proceedings of the IEEE, Vol. 85, No. 11, November 1997

and diode arrays).

Note: Often the terms electro–optical, electrooptical, and electrooptics are used with the identical meaning of optoelectronics. From a detection standpoint, the term optoelectronics seems to be more logical, because a detection sequence goes from the optics to the electronics.

Optoelectronic devices (also photonic devices). Refer to systems in which the photon, the basic unit of light, is affected. There are four basic groups of optoelectronic devices:

- Photodetectors and solar cells – that convert photons into an electrical current
- Light–emitting diodes (LEDs) and semiconductor lasers – that convert an applied voltage into emitted photons
- Optical waveguides – that guide light between a light source and a detector
- Liquid–crystal displays – that use an applied voltage to change the reflection of light.

Optoelectronic detection (pushbroom scanner). The scanner uses a line detector to scan the cross–track direction of a scene, the total field of view of the line is detected (imaged) simultaneously. The number of pixels is equal to the number of ground cells for a given swath. The motion of the platform (airborne or spaceborne) provides coverage in the along–track direction. When a 2–D line detector is used (several lines of detectors in the cross–track direction), then one dimension (cross–track) represents usually the spatial dimension, while the other is used for different spectral bands (multispectral imaging). Examples of pushbroom scanners are: HRV on SPOT series of CNES, LISS on the IRS satellite series of ISRO, AVNIR on the ADEOS S/C of NASDA, MSU on the RESURS series of Russia, ALI of the EO–1 satellite of NASA.

Optomechanical detection (whiskbroom scanner). A form of radiation detection, employing an oscillating or rotating mirror to a line–scanning whiskbroom scanner. On–axis optics or telescopes with scan mirrors sweep from one edge of the swath to the other. The FOV of the scanner can be detected by a single detector or an along–track line–detector. Typical examples of optomechanical scanners are: TM and ETM+ of the Landsat series, AVHRR on the NOAA/POES series, SeaWiFS on Orbview–2 (formerly named SeaStar), ASTER and MODIS of the Terra satellite.

Laser scanners (i.e. active lidar systems) utilize also **optomechanical scanner assemblies** just as many multispectral whiskbroom scanners. However, as active sensing systems, they are using a laser beam as a sensing carrier. Two optical beams must be considered, namely the emitted laser beam and the received portion of that beam.

Orbit types and terminology. See chapter Q.10.

- LEO (Low Earth Orbit)
- MEO (Medium Earth Orbit)
- GEO (Geostationary Orbit)
- HEO (Highly Elliptical Orbit).

The **Molniya** orbit (invented by Russian engineers in the 1960s) is an example of HEO with extremely useful characteristics, specifically of long dwell times over fixed locations and the ability to “self–clean” or deorbit the satellite at the end of its life to reduce space debris. In particular, the Molniya orbit has a long dwell time in the apogee phase. A Molniya orbit has a period of half a day, which places the apogee over two locations on the Earth each for about 8 hours a day.

Molniya orbits are inclined at 63.4°. This inclination is called the critical or “frozen” inclination because the extra gravity pull caused by the Earth’s bulge at equator is balanced on both

sides of the orbit. Therefore satellites at this critical inclination do not experience the effect called the “rotation of apsides” caused by the oblateness of the Earth. The significance is that the ground track of the satellite will not experience the drift that other elliptical orbits experience, and the Molniya satellite will reach its apogee over the same two spots of the Earth each day.

The **Tundra** orbit is an adaptation of the Molniya orbit, first used by Sirius Satellite Radio to provide continuous satellite coverage to North America. Like the Molniya, the Tundra orbit is inclined at the critical angle of 63.4° , but the Tundra orbit has a period equal to one sidereal day. Therefore a Tundra satellite has an apogee dwell of about 16 hours over the same spot every day.

Orbital period. The orbital period is the time a satellite takes to make one complete trip through its orbit around the Earth. Satellites in LEO rapidly orbit the Earth. A satellite in a circular orbit 800 km above the Earth has a period of just 101 minutes. At that rate, the satellite will orbit the Earth 14 times in a day. – By increasing the altitude of the orbit, the period increases. At a distance of 35,786 km, a satellite’s period is equal to one sidereal day (23 hours, 56 minutes, 4.09 seconds), which is the altitude of GEO or GSO (Geosynchronous Orbit).

Orographic phenomena. Meteorological events (precipitation, special winds, clouds, fronts, etc.) associated with the disposition and character of hills and mountain ranges (distribution effects the linked to the form of the terrestrial relief). Orographic precipitation results from the lifting of moist air over an orographic barrier; however, it is not limited to the ascending ground, but may extend for some distance windward of the base of the barrier. Orographic lifting refers to the deflection of an air current up and over mountains. Examples of orographic winds are: Föhn, Mistral, Bora, Santa Ana.

Orthographic projection. A projection in which the projecting lines are perpendicular to the plane of projection (also referred to as orthogonal projection).

Orthophotography. A digital orthophoto is a raster image, which has been accurately scanned and rectified with the aid of geodetic surveying and photogrammetry.

Orthorectification. (orthorectified imagery)

Ozone. A molecule made up of three atoms of oxygen (O_3). Ozone strongly absorbs UV radiation in the wavelength range of 290 – 300 nm. In the stratosphere, it occurs naturally and provides a protective layer (ozone layer between ~ 12 – 30 km in which ozone is relatively concentrated $> 10^{12}$ molecules/cm³) shielding the Earth from ultraviolet radiation and subsequent harmful health effects on humans and the environment. In the troposphere, it is a chemical oxidant and major component of photochemical smog. Ozone is an effective greenhouse gas especially in the middle and upper troposphere and lower stratosphere. – The **depletion of ozone** in polar latitudes is attributed to a sequence of chemical reactions involving chlorine and bromine compounds. These sources are simple organic compounds containing chlorine, e.g. chlorofluorocarbons (CFCs), and/or bromine (e.g. halogens). Nearly all of the chlorine and about half of the bromine in the stratosphere originates from human activities.

Paleoclimatology.⁶⁹⁴⁴ Science which deals with past climate periods of the Earth in very large space–time scales. Long–term baselines of past climate changes are studied and reconstructed to understand climate processes and predict future climate change (climate models). Paleoclimate data are derived from ice cores, tree rings, marine and lake sediments, fossil pollen, plant macrofossils, paleovegetation, past sea surface and lake level data, terrestrial ice sheet height and extent, land surface properties, etc.

6944) D. M. Anderson, R. S. Webb, J. T. Overpeck, B. A. Bauer, “The NOAA Paleoclimatology Program,” NOAA Earth System Monitor, Vol. 3, No. 3, March 1993, pp. 6–8

Panchromatic band. A band of a sensor–detector system which covers the entire width of a spectral range, in particular the visible range (VIS). Panchromatic imagery is grayscale.

Parallax. Apparent change in the position of an object due to an actual change in the point of view of observation. Example application: In optical stereo observation the parallax between two images, viewed from different angles, is used to derive the third dimension of altitude. This topographic information is used for map–making.

Particle precipitation. Refers to the release of charged particles, stored in the Earth’s magnetosphere, into the atmosphere. The particles follow magnetic field lines. They cause a glow (creating an aurora) when they strike the atoms of the upper atmosphere.

Passive radar. In a passive radar system, there is no dedicated transmitter. Instead, the receiver uses third–party transmitters in the environment, and measures the time difference of arrival between the signal arriving directly from the transmitter and the signal arriving via reflection from the object. This allows the bistatic range of the object to be determined. In addition to bistatic range, a passive radar will typically also measure the bistatic Doppler shift of the echo and also its direction of arrival. These allow the location, heading and speed of the object to be calculated. In some cases, multiple transmitters and/or receivers can be employed to make several independent measurements of bistatic range, Doppler and bearing and hence significantly improve the final track accuracy.⁶⁹⁴⁵⁾

Passive sensor. A sensing system that detects and measures incoming radiation emitted by the target. Such sensing systems do not emit any power to the target for purposes of measurement. Hence, passive sensors are sensitive to radiation of natural origin, usually reflected sunlight or energy emitted by an object. Examples of passive sensors are: cameras, multispectral scanners, and radiometers.

Peltier effect coolers. They work on the principle of the thermoelectric effect. Such coolers are thermodynamically reversible low impedance devices, operating at a high current from a DC power supply. A single stage cooler can typically achieve a temperature of -40°C , and lower temperatures can be achieved using several stages. A six stage device may achieve -100°C and give a cooling power of around 1 mW at -80°C . Peltier coolers are by their very nature vibration–free.

Perigee. The point in an orbit at which the spacecraft is nearest to the Earth.

Permanent Scatterers (PS):^{6946) 6947) 6948) 6949)} PS are radar targets exhibiting stable radar returns: man–made objects, pipelines, poles, outcrops, rocky areas, aquifer systems, etc. The PS technique utilizes the coherent radar phase InSAR (Interferometric Synthetic Aperture Radar) data from thousands of individual radar reflectors on the ground to develop a displacement time series. The PS analysis technique is being used to determine minute surface deformation features caused by various tectonic, geomorphic, and hydrologic processes. For instance, the PS technique may be used to measure the uplift of a region which is due mainly to sub–mm/yr tectonic upheaval related to slip along and interaction of the complex array of the San Andreas transform system faults, while seasonally recharging aquifers account for tens–of–millimeter rise. Observed surface downward motions are caused by seasonally depleting aquifers. InSAR data from Earth–orbiting spacecraft has revolutionized the field of crustal deformation research since its first geophysical application which started in the early 1990s.

6945) http://en.wikipedia.org/wiki/Passive_radar

6946) D. Massonnet, M. Rossi, C. Carmona, F. Adragna, G. Peltzer, K. Feigl, T. Rabauté, “The displacement field of the Landers earthquake mapped by radar interferometry,” *Nature*, Vol. 364, 1993, pp. 138–142.

6947) D. Massonnet, K. L. Feigl, “Radar interferometry and its application to changes in the Earth’s surface,” *Reviews of Geophysics*, Vol. 36, No 4, 1998, pp. 441–500.

6948) C. Colesanti, A. Ferretti, F. Novali, C. Prati, F. Rocca, “SAR monitoring of progressive and seasonal ground deformation using the permanent scatterers technique,” *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 41, No 7, July 2003, pp. 1685–1701.

6949) A. Ferretti, “Key drivers for InSAR applications: the Italian case study,” *EOBN 2008 (Earth Observation Business Network)*, May 13–14, 2008, Richmond, BC, Canada

Phase modulation (PM). Angle modulation in which the phase of a sine wave carrier is caused to depart from the carrier phase by an amount proportional to the instantaneous value of the modulating wave.

Phased–array technology. Phased arrays are random–access devices (antennas) employed for electronic beam–steering applications in the microwave and/or optical regions of the spectrum. The technology of electronic beam–steering overcomes many limitations of mechanical beam steering (in particular the motion of masses), offering such capabilities as very precise stabilization ($< \mu\text{rad}$), rapid random–access pointing over a wide field of regard (inertialess steering of beams), programmable multiple simultaneous beams, and other capabilities. In an active phased array system (such as a microwave antenna) individual transmit elements form and direct a beam into a particular direction (2–D steering). The field intensity across the aperture of an active microwave array is generally tapered at the edges to achieve low sidelobe levels. In some radar (SAR) applications the phased array concept is also referred to as **ScanSAR** with the capability to extend the regular swath width (see also **phased–array antenna** under **antenna**).

Photodetector. A semiconductor device that transforms radiation (photons) into an electrical signal. There are two basic types of photodetectors: photodiodes and photoconductors.

Photodiode. Refers to a semiconductor diode which receives incident radiation thereby becoming a photodetector. Principle of operation: Photons (energy) incident on the photodiode (p–n junction) form electron–hole pairs in the detector material (silicon, for instance) when they are absorbed. Manipulation of the electron–hole pairs produce an output signal proportional to the amount of energy received. The time–varying signal represents the total amount of energy it receives. An important measure of how well the device converts photons to electrons is the **quantum efficiency (QE)**. – Silicon is virtually transparent to radiation in the IR range. However, in the UV and VNIR range (0.2 – 1.1 μm), radiation has enough energy (i.e. photon absorption can take place) to create electron–hole pairs. There are several kinds of semiconductor photodiodes; they all work on the same principle which is based on photoconductivity.

Photoelectric cell (or photocell). A detector (transducer) which converts electromagnetic radiation from the UV, VNIR regions of the spectrum into electrical quantities such as voltage, current, or resistance.

Photogrammetry. A large field in remote sensing applications using image surveys (initially photographs) from airborne sensors and producing (topographic) maps from these images (along with position data). Photogrammetry employs photographs (or digital imagery today) to “obtain projection measurements.” In 1759, Johann Heinrich Lambert (1728–1777), in a treatise “*Perspectiva Liber*” (the free perspective or treatise on perspective), developed the first mathematical principles of a perspective image using space resection to find a point in space from which a picture is made. The history of photogrammetry, from around 1850, has experienced four distinct development cycles:

- Plane table photogrammetry, from about 1850 to 1900. In 1849, the French army officer Aimé Laussedat (1819–1907) was the first person to use terrestrial photographs for topographic map compilation. He is referred to as the “father of photogrammetry”. The process Laussedat used was called “iconometry” [icon (Greek) meaning image, –metry (Greek) which is the art, process, or science of measuring].
- Analog photogrammetry, from about 1900 to 1960. In Canada, Edouard Deville (1849–1924) invented the first stereoscopic plotting instrument, the StereoPlanigraph, in 1896. In 1901, Carl Pulfrich (1858–1927) of Carl Zeiss, Jena, designed the first stereocomparator employing x and y coordinates, the first photogrammetric instrument manufactured by Zeiss. Carl Pulfrich developed also the first photogrammetric balloon–borne camera in 1910. Later, aerial survey techniques became a standard procedure in mapping.

- Analytical photogrammetry, from about 1960. This field is closely associated with the development of the computer age and its computational capabilities (coordinate transformations, mapping, etc.). An important development was the first analytical plotter with servocontrol, designed in 1957 by U. V. Helava (1923–1994, born in Finland) at the NRC (National Research Council) in Canada. The first operational photo triangulation program became available in the late 1960s. The data processing capabilities permitted also the generation of the first DEMs (Digital Elevation Models).
- Digital photogrammetry, from about the 1990s onwards. The information technology, in particular the fields of GIS (Geographic Information System) and CAD (Computer Aided Design), have greatly contributed to the development of digital photogrammetry. The main idea of this concept is to use digital images, scan the model area with a 3–D “floating mark” with sub–pixel accuracy. Then use a digital workstation to compile the required features to form an intelligent description for an information system such as GIS and CAD systems. One of the very promising applications within such an integrated raster/vector environment, is the ability of using multi–temporal change analysis to update raster/vector based GIS data. – First applications of this new technique of digital photogrammetry such as digital orthophoto, monoscopic map revision, auto digital elevation models (DEM), and AAT (Automatic Aerial Triangulation) are already operational at the turn of the 21st century, and the system development in other areas such as feature extraction is emerging.⁶⁹⁵⁰⁾

Background: The term “photogrammetry” was first coined and published in 1893 by the German architect Albrecht Meydenbauer (1834–1921). In 1858, he had the idea to replace the conventional reconstruction survey of historical buildings and monuments (perspective rectification plots) by using “photography geometry” for cultural heritage preservation (the measurement principle used ray–tracing in photographs to obtain metric images). In 1885, the Royal Prussian Archive of Monuments (Königlich Preußische Meßbildanstalt) was founded in Berlin with Meydenbauer as its first director.⁶⁹⁵¹⁾

The ASPRS definition is: “Photogrammetry is the art, science and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patterns of electromagnetic radiant energy and other phenomena.”⁶⁹⁵²⁾

In the past, spaceborne imagery was not (or hardly) used for map making due to insufficient spatial resolution; this certainly changed with the availability of high–resolution imagery (<3m) starting from about 1998. Spatial imagery resolutions from satellites are classified as:

- Very low: for pixel sizes greater than or equal to 300 m
- Low: for pixel sizes between greater than or equal to 30 m and < 300 m
- Medium: for pixel sizes between greater than or equal to 3 m and <30 m
- High: for pixel sizes between greater than or equal to 0.5 m and <3 m
- Very high: for pixel sizes <0.5 m

Photomultiplier. A photoemissive detector in which amplification is obtained by secondary emission.

Photon. A particle description of electromagnetic radiation, which can exhibit the behavior of either waves or particles.

6950) M. Madani, “Importance of Digital Photogrammetry for a complete GIS,” 5th Global Spatial Data Infrastructure Conference, Cartagena, Columbia, May 21–25, 2001

6951) K. Schwidewsky, “Albrecht Meydenbauer – Initiator der Photogrammetrie in Deutschland”. *Bildmessung und Luftbildwesen* Vol. 39, No 5, pp. 183–189, 1971

6952) E. M. Mikhail, “Is Photogrammetry still Relevant?,” *PE&RS*, Vol. 65, No 7, July 1999, pp. 740–751

Photon–counting techniques. In a detector with a gain of the order of 10^6 to 10^8 and a pulse response width of the order of 1 ns, each detected photon yields an output current pulse of some mA peak amplitude. The output signal for a low level signal is then a train of random pulses the density of which represents the light intensity. Therefore, counting the detector pulses within defined time intervals – i.e. photon counting – is the most efficient way to record the light intensity with a high gain detector. ^{6953) 6954)}

Several techniques of photon–counting are in use:

- Steady state photon counting
- Gated photon counting
- Multichannel scalars
- TCSPC (Time–Correlated Single Photon Counting)
- Multi–detector TCSPC
- Photon counting for fluorescence correlation spectroscopy

The most common detectors for low level detection of light are **PMT** (Photomultiplier Tubes). A similar gain effect as in the conventional PMTs is achieved in the **MCP** (Microchannel Plate) detector. In fact, the MCP device is the fastest photon counting detector currently available. Moreover, the MCP technique allows to build position–sensitive detectors and image intensifiers.

Photonics is the science of generating and harnessing light as well as other forms of radiant energy whose quantum unit is the photon. Light can transmit, distribute and process digital information quickly and in high volumes. Moreover, it plays an important role for precise measurement, fine processing and diagnosis by interacting with various materials or media. Photonics is a field of intensive research by many institutions. At the start of the 21st century, photonics has become an enabling technology in many fields such as in: metrology, remote sensing, communications, networking, computer science, and medicine. – Photonic devices and components include: optocouplers, LEDs (Light Emitting Diodes), laser diodes, optical fibers, modulators, detectors, fiber optic links and accompanying conditioning devices.

The optical fiber, being a physical medium, is subjected to perturbation of one kind or the other at all times. It therefore experiences geometrical (size, shape) and optical (refractive index, mode conversion) changes to a larger or lesser extent depending upon the nature and the magnitude of the perturbation. In communication applications one tries to minimize such effects so that signal transmission and reception is reliable. On the other hand in fiber optic sensing, the response to external influence is deliberately enhanced so that the resulting change in optical radiation can be used as a measure of the external perturbation.

In communication, the signal passing through a fiber is already modulated, while in sensing, the fiber acts as a modulator. It also serves as a transducer and converts measurands like temperature, stress, strain, rotation or electric and magnetic currents into a corresponding change in the optical radiation. Since light is characterized by amplitude (intensity), phase, frequency and polarization, any one or more of these parameters may undergo a change. The usefulness of the fiber optic sensor therefore depends upon the magnitude of this change and our ability to measure and quantify the same reliably and accurately.

6953) Photomultiplier Tube, Hamamatsu Photonics, 1994

6954) W. Becker, A. Bergmann, “Detectors for High–Speed Photon Counting,” <http://www.becker-hickl.de/pdf/spcdelect1.pdf>

Photonic technologies in the form of fiber optics, integrated optics and micro-photonics have some unique properties as shown in the following summary: ⁶⁹⁵⁵⁾ ⁶⁹⁵⁶⁾ ⁶⁹⁵⁷⁾

- Practically limitless bandwidth (BW) as fiber optics offer an exploitable capacity of several THz at the band around 1550 nm
- Practically lossless propagation in an optical fiber within a spacecraft
- Transparency to any modulation/coding format
- They are immune to EMI (Electromagnetic Interference) and do not induce EMI; ideal for the microwave environment
- Are light weight, low volume
- Are mechanically flexible
- An electrically passive sensor with ideal galvanic isolation (no arc-over).

These properties are especially desired in S/C engineering due to the special conditions in technical and economic terms on building and operating a S/C. The importance of each of these properties varies depending on the specifics of each mission.

- Photonic communications: Satellite payloads either in the form of a telecommunication repeater or a scientific instrument, especially in Earth observation satellites, handle or produce Gbit/s of data. – The most advanced payload scenarios for future telecommunication satellites are used as a reference for the development of high speed photonic links. It is anticipated that such satellites will handle up to 200 spot beams, each beam with 0.5 GHz to 1 GHz BW. Sampling 1 GHz BW in the Nyquist rate with 10 bit/sample plus extra coding for the transmission results in a raw data stream of 25 Gbps and a total throughput from the ADC (Analog to Digital Converter) to the DSP (Digital Signal Processor) of 5 Tbit/s.
- BFN (Beam Forming Network): BFNs are employed to create the desired antenna beam pattern. As modern satellite designs call for intense frequency re-use through multiple spotbeams, BFNs acquire a significant role. The challenge for photonics is to provide the BFN functionality by a very small form BFN fabric based on microphotonic technologies.
- Photonic sensing: The new **FOS** (Fiber Optic Sensor) applications exhibit some unique characteristics that make them very suitable for spacecraft applications. These are primarily their capability:
 - to multiplex a large number of sensors along a single optical fiber
 - to perform sensing of different physical/chemical parameters along the same fiber
 - to permit embedding and integration in structures during their manufacturing
 - to operate in intense EMI environments where other sensors would not be able to operate with the required performance
 - To provide redundancy by being interrogated at either end of the fiber in the case of a multiplexed line of **FBG** (Fiber Bragg Grating) sensors.

The first spaceborne demonstration of the FOS technology is being demonstrated on the PROBE-2 minisatellite of ESA (launch planned for 2009).

⁶⁹⁵⁵⁾ Nikos Karafolas, Josep Maria Perdigues Armengol, Iain Mckenzie, "Introducing Photonics in Spacecraft Engineering: ESA's Strategic Approach," Proceedings of the 2009 IEEE Aerospace Conference, Big Sky, MT, USA, March 7-14, 2009

⁶⁹⁵⁶⁾ <http://www.sensorland.com/HowPage072.html>

⁶⁹⁵⁷⁾ "Fibre Optic Sensor for Measuring the Distribution of Temperature, Strain and Vibration," URL: http://www.technology-forum.com/fileadmin/technologies/1201716316_1069.pdf

Photosphere. Refers to the layer surrounding the sun from which visible light is emitted into space.

Photosynthesis. The conversion of inorganic matter into organic matter by plants, using light as the energy source. Light energy absorbed by **chlorophyll** is used to manufacture carbohydrates (sugars) and oxygen from carbon dioxide (CO₂) and water. Photosynthesis is dependent upon favorable sunlight, temperatures, plant nutrients, and additionally, on soil moisture and carbon dioxide concentration for terrestrial plants. Increased atmospheric levels of carbon dioxide can increase photosynthesis in many land plants. Photosynthesis is responsible for the generation of all atmospheric oxygen. The photosynthetic generation of organic matter is also called ‘primary production.’

Photovoltaic effect, photoconductive effect. Refers to the direct conversion of solar radiation into electrical energy. The photovoltaic effect is achieved when a photon–produced electron–hole pair is separated by a space charge field (p–n junction diode) thus producing a photocurrent. Solar cells are photovoltaic devices. The photovoltaic effect was first reported by the French scientist Alexandre Edmond Becquerel (1820–1891) in 1839. He observed a voltage between two electrodes in a beaker of electrolyte when the beaker was exposed to sunlight. – The photoconductive effect occurs when a bias voltage is applied across a uniform piece of detector material. The photocurrent is then proportional to the density of electrons excited into the conduction band by the incoming photons.

Phytoplankton. The assemblage of microscopic algae (diatoms, flagellates, etc.) in aquatic ecosystems that drift passively with currents (plankton = wandering). The “grass” of the sea, upon which virtually all marine life depends (see also **chlorophyll**). The phytoplankton of the oceans plays a major role in pulling CO₂ out of the atmosphere. The phytoplankton uses the energy of the sunlight to split water molecules into atoms of hydrogen and oxygen. In the process, the oxygen is liberated as a waste product and makes possible all animal life on Earth, including our own. The Earth’s cycle of carbon (and, to a large extent, its climate) depends on photosynthetic organisms using the hydrogen to help convert the inorganic carbon in CO₂ into organic matter (the conversion of CO₂ into organic matter is also referred to as “primary production”). Phytoplankton draw nearly as much CO₂ out of the oceans and atmosphere as all land plants do. ⁶⁹⁵⁸⁾

Piezoelectricity is the charge which accumulates in certain solid materials (notably crystals, certain ceramics, and biological matter such as bone, DNA and various proteins) in response to applied mechanical strain. The word piezoelectricity means electricity resulting from pressure. It is derived from the Greek piezo or piezein, which means to squeeze or press, and electric or electron, which stands for amber – an ancient source of electric charge. Piezoelectricity is the direct result of the **piezoelectric effect**. ⁶⁹⁵⁹⁾

The piezoelectric effect is voltage generation as a result of externally input forces or material deformation. This effect is usually exploited in sensor applications. In contrast, the converse piezoelectric effect generates forces and deforms materials as a result of input electric charges or voltages. This effect is often exploited in transducer applications. ⁶⁹⁶⁰⁾

Pitch. With regard to detector technology, pitch refers to the distance between the center of two adjacent pixels in an array.

Pixel (Picture Element). The smallest area unit of an image which is generated by a single digital measurement (see also **image**). A pixel is a single cell in the grid of a bitmapped image. A rectangular collection of pixels is said to be a raster image and is used to encode digital video. Each pixel has a unique position within an image. Its numerical value is taken arti-

6958) P. G. Falkowski, “The Ocean’s Invisible Forest,” *Scientific American*, Aug. 2002, pp. 38–45

6959) “Piezoelectricity,” URL: <http://en.wikipedia.org/wiki/Piezoelectricity>

6960) Kanjuro Makihara, Shinsuke Takeuchi, Shigeru Shimose, Junjiro Onoda, Kenji Minesugi, “Digital Self–powered Semi–active Unit for Advanced Energy–recycling Vibration Suppression,” Proceedings of the 61st IAC (International Astronautical Congress), Prague, Czech Republic, Sept. 27–Oct. 1, 2010, IAC–10.C2.5.6

ficially from complete or partial resolution cells, sometimes also referred to as ‘image point.’

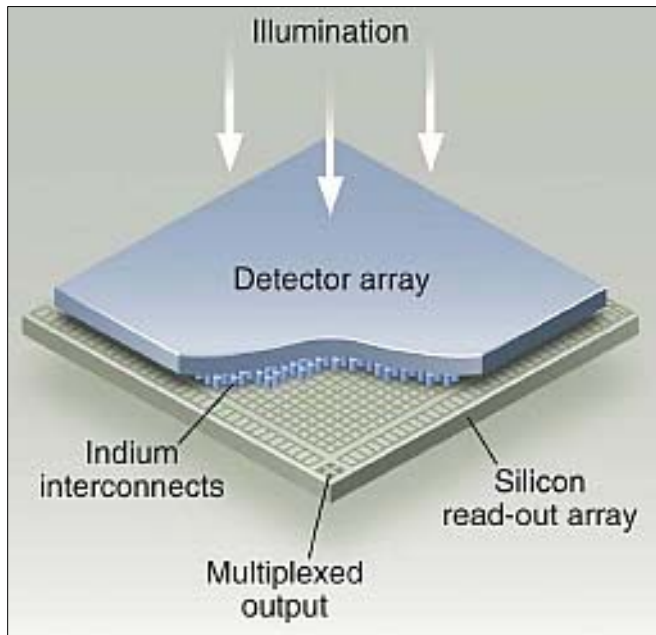


Figure 1598: Illustration of a hybrid infrared detector architecture

Pixel size. Refers to the dimension of one detector pixel of an array. The pixel size is a technical parameter that relates to resolution, process feature dimensions and pixel architecture. For a given die size, a high resolution requires a small pixel. Smaller pixels, however, imply less detector area for in-pixel processing elements (hence reduced SNR and reduced sensitivity). In the case of infrared radiation it means also smaller Indium-bumps for contact between the IR sensor and the CMOS read-out. Large pixels have in general good SNR and sensitivity but suffer from aliasing.

A mature interconnect technique for an infrared detector array is shown in Figures 1598 and 1599.

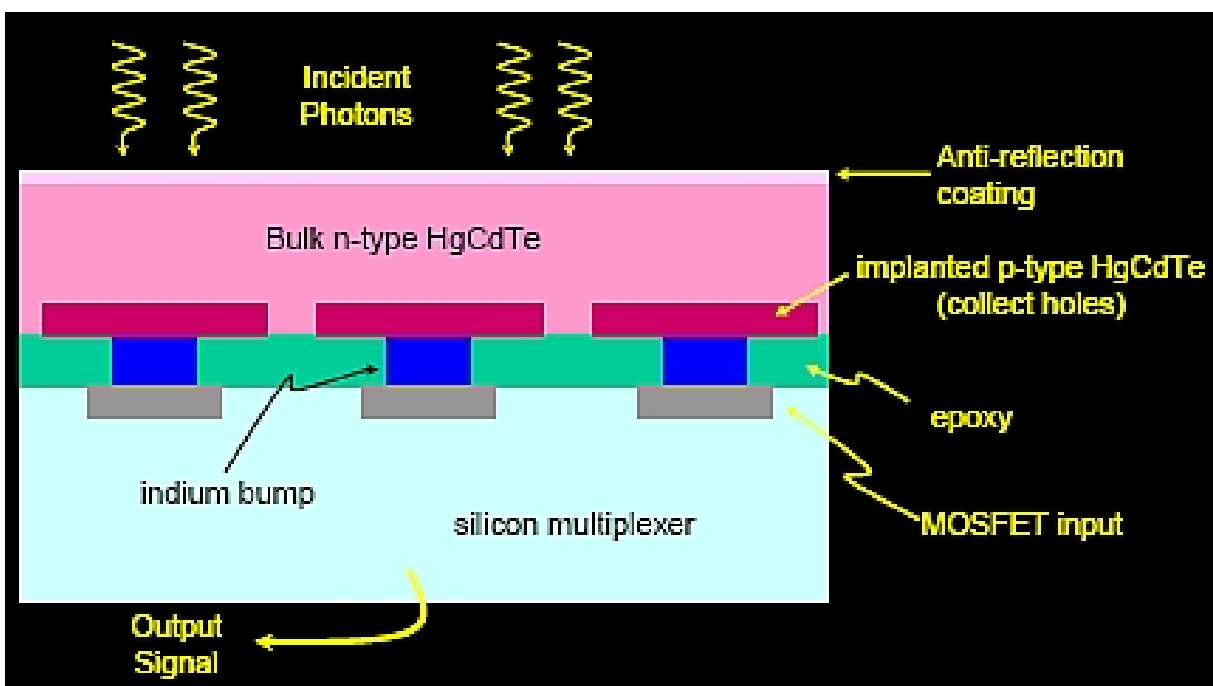


Figure 1599: Cross-section of a HgCdTe FPA (Focal Plane Assembly) with the substrate removed

Pixel value. The digital radiation value of a pixel, expressed as a digital number (DN) or digital count (DC), radiance value, reflectance or other radiation value.

Planetary albedo. The fraction of incident solar radiation that is reflected by a planet and returned to space. The planetary albedo of the Earth–atmosphere system is approximately 30%, most of which is due to backscatter from clouds in the atmosphere.

Planetary Boundary Layer (PBL). Defined as the atmosphere between the Earth’s surface and the free atmosphere. It is directly affected by the properties of the Earth’s surface and surface forcings, such as frictional drag, evapotranspiration, heat transfer, pollutant emission, and topography. See also **Atmospheric Boundary Layer**.

Planetshine. The phenomenon known as “planetshine” occurs when reflected sunlight from a planet illuminates the night side of one of its moons. Typically, this results in the moon’s night side being bathed in a soft, faint light. The best known example of planetshine is **Earthshine**, which can be seen from Earth when the Moon is a thin crescent. Planetshine has been observed elsewhere in the solar system: in particular, it has recently been used by the Cassini space probe to image portions of the moons of Saturn even when they are not lit by the Sun.

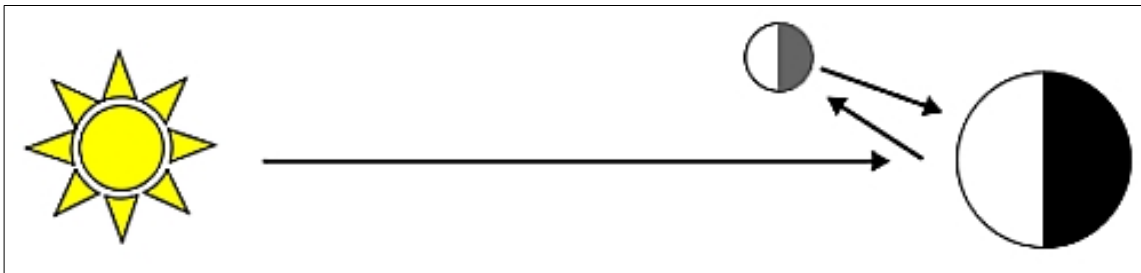


Figure 1600: Schematic view of the Earthshine diagram (image credit: NASA)

Leonardo Da Vinci explained the phenomenon nearly 500 years ago. He realized that both Earth and the Moon reflect sunlight. But when the Sun sets anywhere on the Earth–facing side of the Moon (this happens every 29.5 Earth–days) the landscape remains lit — illuminated by sunlight reflected from our own planet. Astronomers call it Earthshine. It’s also known as the Moon’s “ashen glow” or “the old Moon in the New Moon’s arms.”⁶⁹⁶¹⁾

In more recent observations made with ESO’s VLT (Very Large Telescope) in Chile, the presence of oceans, clouds, atmospheric gases and even plants could be detected in the reflected Earthshine. — The breakthrough method was the use of spectropolarimetry, which measures polarized light reflected from Earth. Like polarized sunglasses are able to filter out reflected glare to allow you to see clearer, spectropolarimetry can focus on light reflected off a planet, allowing scientists to more clearly identify important biological signatures.⁶⁹⁶²⁾

By observing the Moon using ESO’s VLT, astronomers have found evidence of life in the Universe — on Earth. Finding life on our home planet may sound like a trivial observation, but the novel approach of an international team may lead to future discoveries of life elsewhere in the Universe.^{6963) 6964)}

6961) “Earthshine,” NASA, April 12, 2002, URL: http://science.nasa.gov/science–news/science–at–nasa/2002/12apr_earthshine/

6962) “VLT Rediscovered Life on Earth,” ESO, Feb. 29, 2012, URL: <http://www.eso.org/public/news/eso1210/>

6963) Michael F. Sterzik, Stefano Bagnulo, Enric Palle, “The Earth as a benchmark: spectropolarimetry unveils strong biosignatures,” URL: <http://www.eso.org/public/archives/releases/sciencepapers/eso1210/eso1210.pdf>

6964) Michael F. Sterzik, Stefano Bagnulo, Enric Palle, “Biosignatures as revealed by spectropolarimetry of Earthshine,” *Nature*, Vol. 483, pp. 64–66, March 1, 2012, doi:10.1038/nature10778

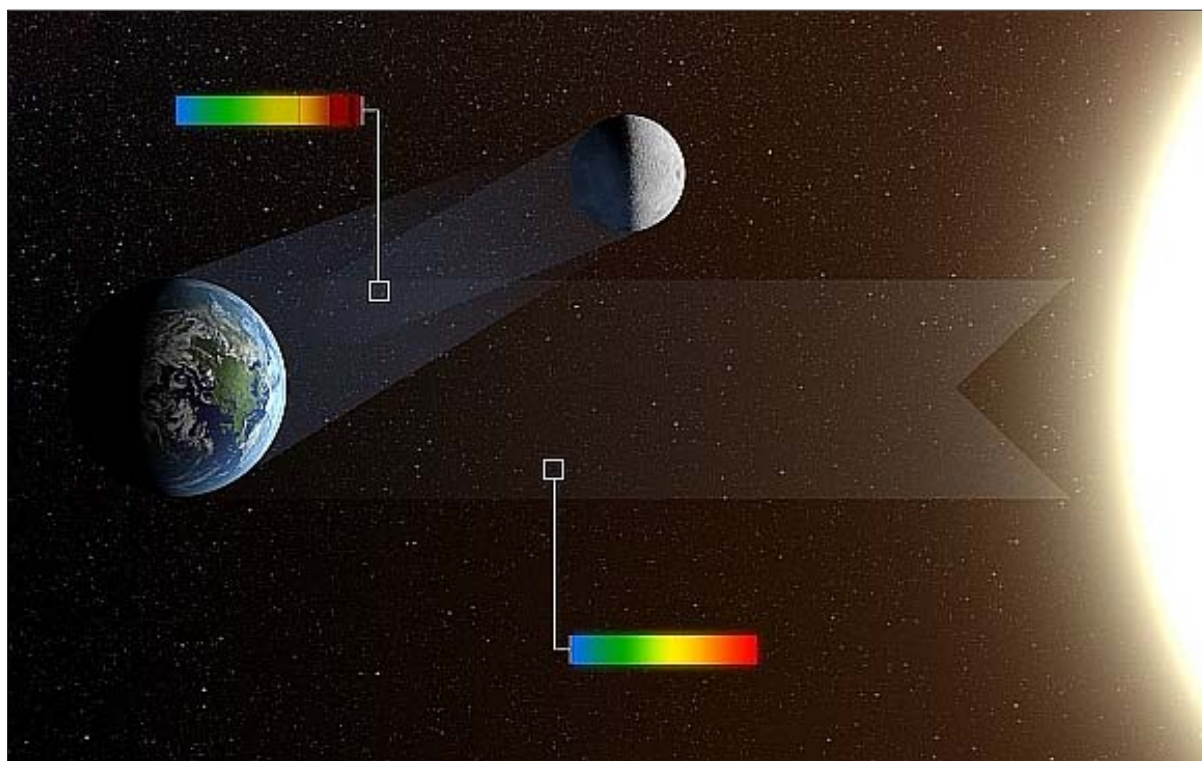


Figure 1601: Earthshine scenario: Spectropolarimetry unveils strong biosignatures (image credit: ESO)

Plasma. A completely ionized gas (a low-density gas), the so-called fourth state of matter (besides solid, liquid, and gas) in which the temperature is too high for atoms as such to exist. A plasma is an electrically neutral gas consisting of charged particles such as ions, electrons, and neutrals. While the temperature of a plasma is very high, its density is very low.

From the magnetosphere of Earth and the atmosphere of stars to the interstellar medium, plasma pervades space. Studying this state of matter consisting of charged particles – electrons, protons, and heavier ions – is vital to our understanding of a range of natural and artificial phenomena.⁶⁹⁶⁵⁾

The properties of plasma are strongly shaped by the presence of magnetic fields. In some cases, this interaction can accelerate particles – mainly electrons – to very high energies. In Earth’s magnetosphere, high-energy electrons can disrupt GPS transmissions and even endanger the health of astronauts involved in spacewalks.

Magnetic reconnection happens at the collision of two flows of plasma with magnetic fields that are oriented in opposite directions. In the process, the magnetic field lines are broken and immediately rearranged in a new configuration; at the same time, two jets of high-speed plasma are launched from the site of magnetic reconnection into opposite directions.

Magnetic reconnection is an efficient mechanism to transfer the energy stored in the magnetic field to the kinetic energy of particles in the plasma. In the Solar System, magnetic reconnection may take place in the solar wind as it travels through interplanetary space, as well as in the magnetosphere of planets that possess a magnetic field.

Plasmoid. Bubble of plasma. Refers to the merging of magnetic lines in the magnetotail which is thought to produce a bubble of plasma, called a plasmoid that flows down the tail during active solar periods.

Pod system A fixture (a foot-like part, a socket, a brace) to fasten something to. Example: an antenna may be mounted in a pod attached under the fuselage of an aircraft A pod struc-

⁶⁹⁶⁵⁾ H. S. Fu, Yu. V. Khotyaintsev, A. Vaivads, A. Retinò, M. André, "Energetic electron acceleration by unsteady magnetic reconnection", 2013, Nature Physics, published online 23 June 2013, DOI: 10.1038/nphys2664

ture may also provide the functions of a service provider. Pod services may include electrical power, cooling, and control systems which differ in concept and detail from pod to pod.

In this context: A **hexapod** is a six-legged structure or a platform supported by six struts. At the start of the 21st century, such structural concepts are gaining increasing attention in the field of “inflatable structures” in space (deployable telescopes, large antenna reflectors, etc.). The goal is to obtain large effective apertures for high-resolution observation functions.

Polarimetry.⁶⁹⁶⁶⁾ Polarimetry deals with the vector nature of polarized electromagnetic radiation throughout the frequency spectrum. The electromagnetic field is a traveling wave (at the velocity of light) with electric and magnetic vector fields perpendicular to each other and to the direction of wave travel. A change in the index of refraction (or permittivity, magnetic permeability, and conductivity) causes the polarization state of a single frequency wave to be transformed, i.e. to be repolarized. Hence, a reflected (scattered) polarized wave from an object such as a radar target must contain some innate information about the object. The interpretation of the behavior of these complex signatures (in particular the direction of the electric field vector of the reflected polarized radiation) is in effect a major objective in polarimetry. In remote sensing polarization measurements are mostly performed in the microwave region of the spectrum. The incorporation of coherent polarimetric phase and amplitude into radar signal and image processing is indeed very promising.

Polarization. Defines the spatial orientation or alignment of the electric (and magnetic) fields of an electromagnetic wave (radiated by an antenna). Horizontal (H) / vertical (V) polarization refers to the electric field (magnetic field) vector’s being parallel / normal to the surface of the medium that the wave is incident upon.

- Like polarization: HH or VV (one component for the transmit and one for the receive signal, as is the case for **active sensors**)
- Cross polarization: HV or VH. Cross polarization requires multiple scattering by the target and therefore results in weaker backscatter than like polarization.
- Alternating dual polarization: alternate transmit and/or receive polarization so that two polarization combinations are measured – e.g. HH and HV or HH and VV.

Polarization is established by the antenna, which may be adjusted to be different on transmit and on receive. Reflectivity of microwaves from an object depends on the relationship between the polarization state and the geometric structure of the object. Possible states of polarization in addition to vertical and horizontal include all angular orientations of the E vector, and time varying orientations leading to elliptical and circular polarizations.

Polarization knowledge offers an additional capability in detecting object characteristics and in discriminating between them, especially in the microwave region of the electromagnetic spectrum (for passive and active sensors). See also **Radar polarimeter**.

Although VV, HH, VH, HV are common terms in “polarimetric radar,” the generally accepted terms differ in **polarimetric radiometry**. Here, the four scalar brightness temperatures are used that make up the complete (modified) Stokes’ vector: $T_v = |E_v|^2$, $T_h = |E_h|^2$, $T_U = 2\text{Re}(T_v T_h^*)$, and $T_V = 2\text{Im}(T_v T_h^*)$.⁶⁹⁶⁷⁾ The modified Stokes vector is related to the (unmodified) Stokes vector as follows: $T_1 = (T_v + T_h)/2$, $T_2 = (T_v - T_h)/2$. Some authors use T_3 and T_4 in place of T_U and T_V to eliminate confusion between the vertical (v) and fourth Stokes parameter (V) indices.

Polar vortex. Refers to the swirling mass of air that appears each year over the Earth’s poles.

6966) W–M. Boerner, H. Mott, E. Lüneburg, et al., “Polarimetry in Remote Sensing: Basic and Applied Concepts,” Chapter 5 (94 p) in R. A. Reyerson, ed., *The Manual of Remote Sensing*, 3rd edition, ASPRS Publishing, Bethesda, MD, 1997

6967) Courtesy of Al Gasiewski of NOAA/ETL in Boulder, CO

Polynya. Polynyas (like leads) are openings in polar region sea ice, they range in size from a few hundred meters to hundreds of kilometers. Polynyas may be formed by two mechanisms: a) forming ice may be continually removed by winds or currents (an example is a shore polynya with offshore winds), b) oceanic heat may enter the region in sufficient quantity to prevent local ice formation.

Precision. The precision of a measurement is a measure of the reproducibility or consistency of measurements made with the same sensor. (The effect of random errors can be reduced by repeated measurement or by averaging, which increases the precision of a measurement).

Preprocessing. Commonly used to describe the correction and processing of sensor data prior to information extraction. For imaging data preprocessing includes geometric and radiometric correction, mosaicking, resampling, reformatting, etc.

Primary productivity. The rate of carbon fixation by marine photosynthetic organisms (phytoplankton). Primary productivity results in the reduction of dissolved inorganic carbon to form organic carbon, with concomitant release of oxygen.

Pseudolites. Refer to auxiliary ground-based transmitters that broadcast GPS-like signals to supplement those generated by the satellites.^{6968) 6969)} The transmitters were initially called “pseudo-satellites,” which was abbreviated to “pseudolites.” System developers used pseudolites as direct replacement for satellites that had not yet been launched, to facilitate system tests. A pseudolite transmits a signal with code-phase, carrier-phase, and data components with the same timing as the satellite signals. A GPS receiver acquires this signal and derives its measurements to be used in a navigation algorithm. Applications are particularly useful for equipment (receiver) tests for such functions as fault detection and isolation, for pseudorange correction (identical to DGPS), and many other practical solutions.

Pseudorandom Noise (PRN). Refers to deterministic binary sequences which are used in spread spectrum communication systems and in ranging systems such as GPS and GLONASS. Two PRN codes are continuously broadcast by GPS satellites: the C/A code and the P-code, both codes modulate the navigation signals. The modulation appears to be random but is, in fact, predictable; hence the term ‘pseudorandom’. The PRN technique allows the use of a single frequency by all GPS satellites and also permits a broadcast of a low-power signal. [Note: The PRN technology was first employed in the 1950s by radio astronomers. With them researchers were able to measure the time delay in the weak radar reflections from the surface of a distant planet – by finding the instant, when the received signals and the transmitted PRN sequences seemed to match most closely.]⁶⁹⁷⁰⁾

Pseudorange. Refers to the range between the antenna phase centers of a GPS satellite and a receiver, measured by the receiver’s delay-lock loop using the C/A-code or P-code. The range is biased by the offset of the clock in the receiver from that in the satellite and by atmospheric propagation delays.

Pulsar. Pulsars are (rotating) neutron stars which emit regular short bursts of detectable electromagnetic radiation in the form of X-ray emissions or radio waves. These short bursts of radio waves are so regular, that they were originally thought to be signals from little green men! – Neutron stars are the remnants of massive stars that have reached the end of their lives. As they rotate they “pulse” and send out a signal in the X-ray band at a regular rate: 30 times a second is typical. The potential of these stable and periodic signals from pulsars was recognized very early by several researchers to provide a high quality celestial clock. In fact, they are considered a celestial time standard.

6968) S. Cobb, M. O’Connor, “Pseudolites: Enhancing GPS with Ground-based Transmitters,” GPS World, March 1998, pp. 55–60

6969) J. M. Stone, et al., “GPS Pseudolite Transceivers and their Applications,” Proceedings of ION National Technical Meeting, San Diego, CA, Jan. 25–27, 1999

6970) T. A. Herring, “The Global Positioning System,” Scientific American, Feb. 1996, pp. 32–38

The radio emission is powered by the rotating magnetic field and focused in two beams stemming from the magnetic poles. As the pulsar rotates, the effect is similar to that of a rotating lighthouse beacon, resulting in distant observers seeing regular pulses of radio waves.⁶⁹⁷¹⁾

The first pulsar (or “pulsating star”) was discovered in 1967, by Susan Jocelyn Bell (a post-graduate student) and Antony Hewish (thesis supervisor) of the University of Cambridge, UK. While using a radio array to study the scintillation of quasars, they found a very regular signal, consisting of pulses of radiation at a rate of one in every few seconds.⁶⁹⁷²⁾

The 1974 Nobel Prize in Physics was awarded to Antony Hewish and Martin Ryle, without the inclusion of S. J. Bell as a co-recipient.^{6973) 6974) 6975)}

The “clocks” in question are actually millisecond pulsars – sun-massed stars of ultra-dense matter that spin hundreds of times per second.^{6976) 6977) 6978)} Due to their powerful magnetic fields, pulsars emit most of their radiation in tightly focused beams, much like a lighthouse. Each spin of the pulsar corresponds to a “pulse” of radiation detectable from Earth. The rate at which millisecond pulsars pulse is extremely stable, so they serve as some of the most reliable clocks in the universe.⁶⁹⁷⁹⁾

Observational data from nine pulsars, including the Crab pulsar, suggest these rapidly spinning neutron stars emit the electromagnetic equivalent of a sonic boom, and a model created to understand this phenomenon shows that the source of the emissions could be traveling faster than the speed of light. Pulsars emit amazingly regular, short bursts of radio waves. Within the emissions from the pulses, the circulating polarization currents move in a circular orbit, and its emitted radiation is analogous to that of electron synchrotron facilities used to produce radiation from the far-infrared to X-ray for experiments in biology and other subjects. In other words, the pulsar is a very broadband source of radiation.⁶⁹⁸⁰⁾

Pulsar signals for celestial (deep space) navigation: The naturally occurring “space clocks” of pulsars represent a **passive signal source** in the electromagnetic spectrum. Each pulsar has a unique frequency and location in inertial space. There are many advantages to using these periodic stellar body X-ray (or radio) signals as navigation references, the main one being stability. In the early 21st century, several institutions around the world (USA, Europe, China) started to investigate this new ‘lighthouse concept technology’ for use in interstellar navigation.

6971) “Volatile Pulsar reveals millisecond missing link,” ESA, Sept. 25, 2013, URL: <http://sci.esa.int/integral/52866-volatile-pulsar-reveals-millisecond-missing-link/>

6972) A. Hewish, S. J. Bell, J. D. Pilkington, P. F. Scott, R. A. Collins, “Observation of a Rapidly Pulsating Radio Source,” *Nature*, Vol. 217, Feb. 1968 p. 709

6973) S. I. Sheikh, “The Use of Variable Celestial X-Ray Sources for Spacecraft Navigation,” 2005 (Ph.D. dissertation at the University of Maryland), URL: <https://drum.umd.edu/dspace/bitstream/1903/2856/1/umi-umd-2856.pdf>

6974) J. Sala, A. Urruela, X. Villares, R. Estalella, J. Paredes “Feasibility study for a spacecraft navigation system relying on pulsar timing information,” ESA ACT (Advanced Concepts Team) Ariadna Study, 03/4202, June 23, 2004, URL: <http://www.esa.int/gsp/ACT/doc/ARI/ARI%20Study%20Report/ACT-RPT-MAD-ARI-03-4202-Pulsar%20Navigation-UPC.pdf>

6975) George Hobbs, Dick Manchester, Simon Johnston, “Fifty years ago Jocelyn Bell discovered pulsars and changed our view of the universe,” *The Conversation*, 27 November 2017, URL: <https://theconversation.com/fifty-years-ago-jocelyn-bell-discovered-pulsars-and-changed-our-view-of-the-universe-88083>

6976) J. Sala, A. Urruela, X. Villares, J. Romeu, S. Blanch, R. Estalella, J. M. Paredes, “Pulsar Navigation,” Jan. 14, 2008, URL: http://www.am.ub.es/~robert/preprints/pulsar_navigation_ACTw_def.pdf

6977) J. Hanson, S. Sheikh, P. Graven, “Noise Analysis for X-ray Navigation Systems,” IEE/ION PLANS (Position Location and Navigation Symposium), Monterey, CA, USA, May 5–8, 2008, URL: http://www.asterlabs.com/publications/2008/Hanson_et_al_IEEE-ION_PLANS_May_2008.pdf

6978) “New Pulsar “Clocks” Will Aid Gravitational Wave Detection,” *Universe Today*, January 5, 2010, URL: <http://www.universetoday.com/2010/01/05/new-pulsar-clocks-will-aid-gravitational-wave-detection/>

6979) “Faster-Than-Light Polarization Currents,” *Space Daily*, Jan. 6, 2010, URL: http://www.spacedaily.com/reports/Faster_Than_Light_Polarization_Currents_999.html

6980) “Faster-Than-Light Pulsar Phenomena,” *Universe Today*, Jan. 6, 2010, URL: <http://www.universetoday.com/2010/01/06/faster-than-light-pulsar-phenomena/>

- DARPA in cooperation with NASA started an XNAV (X-ray Source-based Navigation for Autonomous Position Determination) program in 2005 to develop an alternative navigation approach and capability to GPS (a constellation of man-made signal sources).
- The MPE (Max Planck Institute for Extraterrestrial Physics) is studying navigation concepts with pulsars.⁶⁹⁸¹⁾
- The CSSAR (Center for Space Science and Applied Research) in Beijing is investigating navigation concepts based on XNAV and ultraviolet sensor.⁶⁹⁸²⁾

Pulse Code Modulation (PCM). Any modulation that involves a code made up of pulses to represent binary information. This is a generic term; additional specification is required for describing particular cases.

Quantum communications: In classical information theory, the smallest unit is the bit. In digital computers, the voltage between the plates of a capacitor represents a bit of information: a charged capacitor denotes bit value 1 and an uncharged capacitor bit value 0. The base unit of the quantum computing is the quantum bit (**qubit or qbit**), which is a two-state quantum mechanical system. It can be represented by number of photons (vacuum or single photon state), electronic spins (spin up or spin down), atomic spins (spin up or spin down), etc. In communication, the polarization of a photon is used, i.e., horizontal or vertical polarization.

Quasar (Quasi-stellar object). Refers to the brightest known objects (similar to galaxies) in the universe which emit massive amounts of electromagnetic energy, including light, which shows a very high redshift (a high redshift implies distance). In an optical telescope, quasars appear point-like, similar to stars, from which they derive their name (*quasar = quasi-stellar radio source*) since this type of object was first identified as a kind of radio source. Although they were a mystery for many years, astronomers now believe they are the bright radiation from matter clogging up around an actively feeding supermassive black hole.

The discovery of quasars goes back to the late 1950s when several radio sources were matched with very dim optical objects that looked like stars, but had strange spectra with a lot of ultraviolet radiation. One of them, 3C273 (catalog name, in Virgo), had its position very accurately measured by Cyril Hazard and co-workers, using lunar occultations. In 1962, Maarten Schmidt obtained a spectrum of this "star", which showed a redshift of 0.158. The discovery showed that 3C 273 was receding at a rate of 47,000 km/s. This was when QSO (Quasi Stellar Object) was coined, because this was a very distant object that was masquerading as a star, a quasi-stellar object.⁶⁹⁸³⁾

In the early 21st century, more than 200,000 quasars are known. All observed spectra have shown considerable redshifts, ranging from 0.06 to the recent maximum of 6.4 (corresponding to distances of 780 million to 13 billion light years, respectively). Quasars can be observed in many parts of the electromagnetic spectrum including radio, infrared, optical, ultraviolet, X-ray, and even in the gamma-ray spectrum. Most quasars are brightest in the UV spectrum, near the 121.6 nm Lyman-alpha emission line of hydrogen.

Quasars are thought to be the result of a supermassive black hole at the center of a galaxy attempting to swallow up all of the matter that surrounds it. As the matter bunches up when it gets closer to the black hole, it heats up due to friction and begins to emit light across the electromagnetic spectrum. The light from a quasar can outshine an entire galaxy of stars, making it difficult to separate the light from a background galaxy from the overwhelming glare of the quasar itself.

6981) Werner Becker, Mike G. Bernhardt, Axel Jessner, "Autonomous Spacecraft Navigation With Pulsars," March 13, 2013, astro.ph.HE, URL: <http://arxiv.org/pdf/1305.4842.pdf>

6982) Yang Chengwei, Zheng Jianhua, Gao Dong, "Autonomous orbit and attitude determination including time prediction based on XNAV and ultraviolet sensor," Chinese Journal of Space Science, 2013, Vol. 33, Issue 2, pp: 194–199

6983) http://en.wikipedia.org/wiki/Quasar#History_of_quasar_observation

In 2010, a quasar (quasi–stellar object) has been shown to gravitationally lens a galaxy behind it. About a hundred instances of gravitational lenses that consist of a foreground galaxy and a background quasar have been found, but this is the very first time where the opposite is the case; that is, a **quasar bending the light from a background galaxy around it to create a multiple image of that galaxy.**⁶⁹⁸⁴⁾ The discovery was made by astronomers from EPFL's Laboratory of Astrophysics in cooperation with Caltech using data from the Sloan Digital Sky Survey (SDSS). The Quasar is referred to as QSO: SDSS J0013+1523 at $z = 0.120$. SDSS J0013+1523 lies about 1.6 billion light years away, and is lensing a galaxy that is about 7.5 billion light years away from Earth.

Quasi–optics (QO). QO refers to instruments collecting imagery in the MMW (Millimeter Wave, ≤ 10 mm to 1 mm, equivalent to 30–300 GHz) and the sub–mmw (≤ 1 mm to 0.1 mm, equivalent to 300–3000 GHz) range of the spectrum. Although we think of 'optical' systems as being relevant only at visible and near–visible wavelengths, it turns out that the optical and free space beam methods can be used over a much wider range — namely from below mmw to the sub–mmw region. As a result, signals over most of the “mmw to FIR (Far Infrared)” region can be processed using instruments which employ optical beams in the same way as we might use metal wires or waveguides at lower frequencies.

In general we wish practical systems to be as compact as possible without compromising the performance.^{6985) 6986)} The beams used therefore can't have an enormous cross–sectional width compared with the wavelength. This means that techniques based on Gaussian Beam Mode analysis are often the most appropriate to take diffraction effects into account. Compact systems of this type are often called **quasi–optical** to indicate that their basic elements are 'optical', but a beam mode approach is used to take the effects of finite wavelength into account.

Quantization. The process of converting continuous values of information to a finite number of discrete values. A 10 bit quantization means that the measured signal can be represented by a total of 1024 digital values, say from 0 to 1023.

Quantum Dot (QD). QDs are nanoscale semiconductors that have unique fluorescent properties that allow improved efficiency to be approached from spectrum conversion — they can be used to convert the solar spectrum into spectral content that more closely matches the most efficient wavelengths for photovoltaic conversion of a given device.⁶⁹⁸⁷⁾

A quantum dot has a discrete quantized energy spectrum. The corresponding wave functions are spatially localized within the quantum dot, but extend over many periods of the crystal lattice. A quantum dot contains a small integer number (of the order of 1–100) of conduction band electrons, valence band holes, or excitons, i.e., an integer number of elementary electric charges.

Quantum cryptography. The term describes the use of quantum mechanical effects (in particular quantum communication and quantum computation) to perform cryptographic tasks. Quantum cryptography exploits a unique property of single particles, such as photons: they can exist in two separate states — such as vertically polarized or horizontally polarized — or something in–between, known as a quantum superposition.

Quantum efficiency (QE). A measure of the efficiency with which incident photons are detected (such as a photodiode). Some incident photons may not be absorbed due to reflection

6984) “First Quasar Gravitational Lens Discovered,” *Univers Today*, July 21, 2010, URL:<http://www.universetoday.com/2010/07/21/first-quasar-gravitational-lens-discovered-wvideo/>

6985) Jim Lesurf, “Beam/Waveguide Coupling,” URL: http://www.st-andrews.ac.uk/~www_pa/Scots_Guide/RadCom/part11/page1.html

6986) Irina A Tishchenko, Alexander I. Nosich, “Early Quasioptics of Near–Millimeter and Submillimeter Waves in IRE–Kharkov, Ukraine: From Ideas to the Microwave Pioneer Award,” *IEEE Microwave Magazine*, Dec. 2003, URL: <http://www.ire.kharkov.ua/mwm2003-kuleshov.pdf>

6987) T. G. Stern, “Quantum Dot Technology for Low–Cost Space Power Generation for Smallsats,” *Proceedings of the 20th Annual AIAA/USU Conference on Small Satellites*, Logan, UT, Aug. 14–17, 2006, paper: SSC06–VI–1

or may be absorbed where the electrons cannot be collected. The QE is the ratio of the number of detected electrons divided by the product of the number of incident photons times the number of electrons each photon can be expected to generate. Visible wavelength photons generate one electron–hole pair. More energetic photons generate one electron–hole pair per each 3.65 eV of energy.

Radiation detection – incoherent and coherent detection.⁶⁹⁸⁸⁾ For the detection of thermal emissions in the atmosphere two techniques are in use: the heterodyne technique with coherent detection (in the range UV to about 10 mm) and the detection scheme of the optical range (0.1–1000 μm) with incoherent detection.

The main characteristics of coherent detection are:

- Detection of a single mode of the source radiation; this implies a limited throughput of the instrument
- A very selective frequency separation that allows a very high spectral resolution
- The detection noise is proportional to the square root of the width of the resolved spectral element, that favors the use of high spectral resolution
- The spectral bandwidth and the number of independent spectral elements (bands) simultaneously observed with an instrument are limited by technical constraints

The main characteristics of incoherent detection are:

- Capability of simultaneous detection of several modes, permitting the exploitation of a large throughput
- Possibility of attaining a high spectral resolution
- The measurement noise is proportional to the square root of the width of the instantaneous spectral band – this is applicable in the case of cooled photon–noise–limited detectors
- Possibility of observing a very broad spectral interval with a single instrument.

The cooling of detectors is an option for improved performances.

Radiation hardness (rad). The space radiation environment causes degradation of electronic spacecraft components over time which may eventually result in failure of the electronic and electrical systems. Even high altitude commercial airliners flying polar routes have shown documented cases of avionics malfunctions due to radiation events. Experience with many spacecraft since the Sputnik era shows that higher electron concentrations are observed between 45° and 85° latitude in both the northern and southern hemispheres, indicating that the belts descend to a lower altitude in these regions.⁶⁹⁸⁹⁾ For low inclination orbits, less than 30°, the electron concentrations are relatively low. Due to the Earth's asymmetric magnetic field, a region in the Atlantic near Argentina and Brazil, known as SAA (South Atlantic Anomaly), has relatively high concentrations of electrons. The SAA is known to cause problems such as: single event upsets (SEU) in altimeter electronics gate arrays, and “hard” SEU's in the Space Shuttle Orbiter's Star Tracker's ADC (Analog–to–Digital Converter). The March 1991 solar storms significantly increased the charged particle distributions in the Van Allen belts, also creating a third belt.

To ensure dependable and reliable electronic circuit designs, the radiation environment for TID (Total Ionizing Dose) and SEE (Single Event Effects) encountered at a specific height

6988) B. Carli, U. Cortesi, L. Palchetti, “Infrared Emission Spectroscopy,” J. Demaison et al. (editors), *Spectroscopy from Space*, NATO Science Series, II Mathematics, Physics and Chemistry, Vol. 20, Kluwer Academic Publishers, 2001, pp. 171–186

6989) “Space Radiation Effects on Electronic Components in Low–Earth Orbit,” Practice No. PD–ED–1258, pp.1 – 7, April 1996, NASA/MSFC, www.hq.nasa.gov/office/codeq/relpract/1258jsc.pdf

and orbital orientation during the spacecraft mission must be determined. All electronic devices/components experience two radiation–related effects in space. The first, the TID effect is time dependent, and the second, SEE, depends on many factors and is independent of time. Note: SEUs are transient faults caused by the passage of a single charged particle and typically manifest themselves as a bit–flip – an undesired change of state in the content of a storage element. Radiation induced SEUs are not restricted to the space environment, but also have been observed at ground level.

- For satellites in sun–synchronous LEO (i.e. polar orbiting S/C), typical dose rates due to the increased number of trapped electrons are 1–10 krad (Si)/year.
- For satellites in equatorial LEO (orbits < 30° inclination), typical dose rates due to trapped Van Allen electrons and protons are in the order of 0.1–1 krad (Si)/year.

Standard COTS (Commercial–off–the Shelf) components have a reasonable chance of performing well in this environment.

- Satellites in MEO (Medium Earth Orbit) are drastically more challenging (i.e., 100 krad (Si)/year of TID). They require the use of radiation tolerant or radiation hardened electronic devices to ensure reliability and prevent the electronics from destructive latch–up conditions due to radiation.

The TID of a component may be enhanced by use of intrinsically radiation hard processes such as bulk CMOS, or by the SOI technique, or by shielding more susceptible devices with a high Z material such as tungsten. Radiation hardening for SEU tolerance can involve substantial changes to the device topology to mitigate charged particle effects. The process of radiation hardening is time–consuming and expensive. It is not uncommon for the radiation hardened version of an electronic part to be released five years after the initial commercial part, producing obsolescence on arrival (no state–of–the art performance).

Component Category	Radiation hardness doses (typical)	Description
Commercial	Total ionization dose: 2–10 krad SEU threshold LET: 5 MeV/(mg cm ²) SEU error rate: 10 ⁻⁵ errors/bit–day	Process/design limit the radiation hardness No lot radiation controls Customer evaluation and risk
Radiation tolerant	Total ionization dose: 20–50 krad SEU threshold LET: 20 MeV/(mg cm ²) SEU error rate: 10 ⁻⁷ errors/bit–day	Design assures rad hardness to a level No lot radiation controls Usually tested for functional fail only, risky Customer evaluation and risk
Radiation hardened	Total ionization dose: >200 krad to 1 Mrad SEU threshold LET: 80–150 MeV/(mg cm ²) SEU error rate: 10 ⁻⁷ – 10 ⁻⁸ errors/bit–day	Designed for a hardness particular level Wafer lot radiation tested Latch–up: None present in SOI/SOS (Silicon–on–Insulator/Silicon on Sapphire) CMOS technology. Exhibit low SEU sensitivity for SEE (Single Event Effect)

Table 973: Overview of general radiation hardness categories

Radar (Radio Detection and Ranging). A method, a system, or a technique for using beam, reflected, and timed electromagnetic radiation to detect, locate, and track objects, to measure distance (range), and to acquire terrain imagery. Conventional radar systems comprise a collocated transmitter and receiver, which usually share a common antenna to transmit and receive. A pulsed signal is transmitted and the time taken for the pulse to travel to the object and back allows the range of the object to be determined.

The term ‘radar’ in remote sensing terminology refers to active microwave systems (from about 1 GHz – 100 GHz; most current instruments operate below 10 GHz). The terms ‘Doppler delay’ (range), ‘Doppler gradient’ (range rate), and ‘Doppler frequency analysis’

are important parameters in the formulation of the range–Doppler radar imaging principles. The motion of the sensor–bearing vehicle provides the relative motion between sensor and target required to perform imaging.

Radar systems may be classified by the signal measurement technique employed – there is the **pulsed radar** class and the **FMCW** (Frequency Modulation Continuous–Wave) radar class. The pulsed radar is the most widely used type of radar systems. It is so called because the transmitter sends out pulses of microwave energy with relatively long intervals between pulses. The receiver picks up the echoes of the returned signals; the elapsed time (or run time) is a measure of the distance travelled.

FMCW radar transmits continuous microwave energy – the resultant continuous echo cannot be associated with a specific part of the transmitted signal (hence, range information cannot be obtained). However, the system can determine the speed of a target by measuring the Doppler shift (change in frequency). A more sophisticated continuous–wave instrument, known as ‘frequency–modulated radar,’ is also able to measure range. This is done by tagging each part of the transmitted microwave signal (by continuously changing the frequency), rendering it recognizable upon reception. With the rate of frequency change known, the difference in frequency can be interpreted as a range measurement.

Radar instruments consist of the following major elements: RF electronics, antenna, digital electronics, and recorder. Radar instruments are built for a specific transmission frequency in the microwave spectrum, such as P–band, L–band, S–band, C–band, X–band, Ka–band, etc.; some very advanced instruments offer observation in multiple frequencies.

- **RAR** (Real–Aperture Radar). The term RAR is used because the along–track resolution of a surface image is determined by the actual length of the antenna aperture. In general, the larger the aperture of the antenna (in terms of wavelengths), the narrower will be the beam (along–track resolution is given by the width of the antenna sweep; across–track resolution is determined by the range–resolving capability of the instrument). RAR systems are usually much simpler than SAR systems in design and data processing. RAR–pulsed signals, based on the range–Doppler principle, are not required to be coherent (only the signal amplitude information is recovered and processed), representing and displaying backscatter characteristics from the surface sweep that are recorded on film or on magnetic tape. Microwave energy reflected from the surface terrain (target) is converted by the RAR instrument into electrical signals and recorded as a function of distance (along–track and across–track direction). The radar returns from the different positions in the sweep (and at the different ranges) are separated in time by the radar receiver (the across–track range measurement is a function of signal return time). After reception and recording of the previous pulse, a new pulse is transmitted for a new radar sweep. – The density of the image varies with the surface properties (roughness, moisture content, etc.). The image can be interpreted in terms of the topographical features of the terrain.

- **SAR** (Synthetic Aperture Radar), see also Q.8.2. This radar type permits high–resolution imagery at long ranges (a SLAR device from a satellite orbit is of limited use due to the poor resolution obtained by the angular geometry constraints of the radar beam). A SAR instrument is also referred to as a ‘coherent SLAR.’ – SAR is a concept for complex signal processing techniques to recover an image by the coherent processing of all return signals of all targets (cells) in a single sweep. The cross–track Doppler range of all targets is determined by the signal return time. The pulse bandwidth determines the cross–track or range resolution. Coherence⁶⁹⁹⁰) in this SAR context refers to the fact that the **phase and amplitude** information of the **radar cross section** is measured for all recovered signals. The SAR technique provides resolutions that would normally be associated with an antenna with an

⁶⁹⁹⁰) Note: As coherent pulses transmitted from the radar source reflect from the ground (target) to the advancing SAR instrument (on an aircraft or a spacecraft), the target acts as though in apparent (relative) motion. This motion results in changing frequencies which give rise to variations in phase and amplitude in the returned signals. – Offline processing of these data involves the analysis of the moderated pulses.

aperture far wider than that actually used. — A disadvantage of the SAR observation/processing technique is the generation of very high data rates (between 20 and 100 Mbit/s and more); this implies high communication rates and large storage volumes. On-board recorders are strained to their very limits to handle SAR data. First attempts are being made at real-time onboard preprocessing for the purpose of data reduction. The main elements of a SAR instrument are:

- RF electronics. The RF portion of a SAR system consists of signal generators, high power transmitters (single or combined), low noise receivers, and the associated signal conditioning elements: amplification, filtering, and frequency conversion. Important RF characteristics to a SAR instrument are: large dynamic range with good linearity and low noise floor, good amplitude and phase stability over time and temperature, and high power efficiency.
- SAR antenna. For an Earth observation SAR, the preferred antenna beam casts an elliptical footprint on the ground with an effective rectangular aperture of typical size 10 meters (along-track) and 3 meters (cross-track). Multi-polarization requires dual polarization antennas with good cross-pol isolation. Practically all SAR antenna designs feature a solid flat aperture (antenna and support structure are a dominant mass and volume factor of a SAR instrument).
- Digital electronics. The main functions provided by the digital electronics in SAR are: radar configuration and timing control, radar signal digitization and formatting, radar housekeeping telemetry generation. Sometimes digital processing is performed to reduce the data, and the often coded radar illumination pulse is generated digitally.

Imaging radars (SAR instruments) operate at a specific wavelength or frequency in the microwave region. [This is different from optical instruments which observe radiation in a spectral band (a region of frequencies) or in many spectral bands]. A radar system records the signal response from the ground target at a single specific wavelength (e.g. 15 cm).

Background: The microwave region of the electromagnetic spectrum is generally considered from 1 mm to 1m wavelengths. In analogy to the optical band designations (red, green blue), the microwave spectrum was also given band designations in form of letter references. The military introduced these letter designations in the early days of radar research (mostly for reasons of security during World War II). The remote sensing community seems to adhere to these old “standards” as a means of “ball park reference” designation. Hence, the microwave region includes today such band designations as P, L, S, C, X, K, Ka, etc., for radar (SAR) instruments.

Naturally, the rule of specific wavelength (for frequency) operation of a SAR instrument is not affected by this scheme of letter band designations. Newer SAR instruments operating at multiple frequencies are actually an agglomeration of single-frequency instruments.

- **IFSAR** (Interferometric SAR) – see **Interferometric measurements**
- **SLAR** (Side-Looking Airborne Radar) – an active sensor with RAR technology.
- **Radar altimeter.** An active device observing the vertical distance between the instrument and the ground by measuring the elapsed time between the emitted and returned signals of electromagnetic pulses. Determination (mapping) of the height profile of the surface (topographic applications, in particular of ocean height surfaces).

Note: At the start of the 21st century, satellite radar altimetry data has been used for more than a decade to map the height of the sea surface, which is not actually as flat as one might think. Although invisible to the eye, the sea surface has ridges and valleys that echo (or mimic) the topography of the ocean floor combined with mass anomalies of the Earth’s interior, in several places of the order of tens of meters. For example, the effect of the slight increase in gravity caused by the mass of an undersea mountain attracts extra water over it, causing a ‘bulge’ in the sea surface. Similarly, the reduced gravity over trenches in the sea

floor means there is less water held over these regions, so the height of the sea surface is depressed.

- **Scatterometer.** A scatterometer is a nonimaging radar, distinguished from other radars by its ability to measure radiation amplitude. A radar scatterometer is an active device measuring the backscattering coefficient of the illuminated cell (area or volume under observation) at a specified configuration of incidence angles, wavelengths, and wave polarization orientations. The backscattering (or scattering) coefficient σ^0 describes the target backscattering characteristics (it is defined as the intensity of the power scattered by a 1 m^2 area of a target back toward the radar, relative to the incident power density) and varies as a function of surface roughness, moisture content, and dielectric properties. A rough ocean surface returns a weak pulse because sea surface waves scatter the energy of the microwave pulse in different directions. The scattering reduces the amount of energy which is received back at the satellite. On the other hand, a smooth ocean surface returns a strong pulse because there is very little wave effect. The surface roughness is related to the wind speed. High wind speeds disturb the smooth ocean surface and produce many waves of several cm in size while low wind speeds do not disturb the ocean surface as much and produce much smaller waves. In addition to windspeed, scatterometers (and SARs) measure the direction that waves are moving in relation to the satellite. The direction that the waves are oriented with respect to the radar pulse has an effect on the polarization of the returned signal. – Application: the surface backscattering coefficient may be used to derive the surface wind vector (in particular over oceans). See also **sigma naught**.

- **Lidar** (Light Detection and Ranging) an active sensor system, see Q.8.6. A lidar instrument is also referred to as an ‘optical radar’ [or a ‘laser radar’ – it also goes by the name of ‘**ladar**’ (laser detection and ranging)] since it utilizes the optical (and TIR) portion of the electromagnetic spectrum ($0.3 - 10 \text{ }\mu\text{m}$ wavelength range, or a frequency range of about $1000 - 30 \text{ THz}$). The term Lidar is mostly used in the military context. – A very narrow beam (pulse) of laser light is emitted, the echo is analyzed. Lidar beam divergence is two to three orders of magnitude smaller compared to conventional 5 to 10 cm wavelength radars. This characteristic permits unambiguous velocity measurements near clouds and surface features.

- **Radar polarimeter.**⁶⁹⁹¹ This radar instrument type measures the complex (amplitude and phase) scattering matrix (i.e. the full polarization signature: VV, HH, VH and HV for transmit and receive signals) for every resolution element in an image. Radar polarimetry is therefore an extension of scatterometry, in which the received power of an echo is typically measured for one or more fixed polarization states and a single, or two orthogonal, transmit states. – Knowing the full scattering matrix permits calculation of the receive power for any possible combination of transmit and receive antennas; this process is called polarization synthesis. Hence, the information content derived from a polarimetric radar instrument is far superior to the information yielded by nonpolarimetric devices. Typical airborne polarimetric radar instruments are: ARMAR, CAS–SAR, C/X–SAR, DO–SAR, EMISAR, HUTSCAT, MMW–SAR, NUSCAT, P–3/SAR, IMARC, RAMSES, PHARUS, etc. (see Table 32); a typical spaceborne polarimetric radar instrument is the L/C– Band SAR (JPL) of the SIR–C payload.

Note: Conventional imaging radars operate with a single, fixed–polarization antenna for both transmission and reception of radio frequency signals. In this way a single scattering coefficient is measured for a specific transmit and receive polarization combination for many thousands of points in a scene. A result is that only one component of the scattered wave, itself a vector quantity, is measured, resulting in a scalar characterization of the wave, and any additional information about the surface or volume contained in the polarization properties of the reflected signal is lost.

⁶⁹⁹¹) H. A. Zebker, J. J. van Zyl, “Imaging Radar Polarimetry: A Review,” Proceedings of the IEEE, Vol. 79, Nr. 11, November 1991, pp. 1583–1606

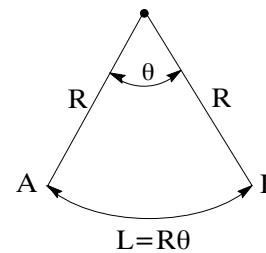
Radar albedo. Ratio of a target's radar cross-section in a specified polarization to its projected area; hence, a measure of the target's reflectivity.

Radar backscatter. Refers to the radar echo; a scattering process of microwave energy by an object/target in the direction of the radar antenna, after actively being irradiated by the radar source.

Radar cross section.⁶⁹⁹²⁾ A hypothetical area of an object of such an extent that if the power intercepted by this area were distributed isotropically over the space, it would render the same power density at the receiving antenna as the power density brought about in reality by the presence of the object or target. Usually, the radar cross-section concerning compound objects (distributed targets) is normalized: either as a radar cross section per unit area (differential scattering cross section or backscatter coefficient σ^0), or as a radar cross section per unit of area projected in the direction of transmission (gamma or scattering cross section).

Radar meteorology. A discipline that uses backscattered electromagnetic radiation within the microwave band to gain information about the state of the atmosphere, especially with respect to clouds and precipitation. The return signal allows the interpretation of four fundamental properties of the spectrum: amplitude, phase, frequency, and polarization.

Radian. The size of angles in classical mechanics is expressed in radians. The concept of radians permits a simple mathematical relationship between the length L of the arc of a circle (i.e. a segment of the circumference) and the angle subtended (enclosed) at the axis by the arc. The arc length L is given by: $L=R\theta$. This means that when the length of the arc is equal to the radius ($L=R$), then θ is one radian (or the angle at the center of the circle subtended by an arc equal to the radius is one radian). In one revolution the arc length is equal to the circumference, so that $L=2\pi R$, or $\theta=2\pi$ radians, or 1 radian = $2\pi/360^\circ \approx 57.28^\circ$. Example: for $R=1000$ m and $\theta=0.2$ radians (FOV), then $L=200$ m (in case of a sensor, the swath width).



Angular size with no distance information is usually the only information available in observational astronomy. Some sample angular sizes are:

- The full moon subtends 30 arcminutes
- The Andromeda galaxy subtends about five degrees

Radiance. Energy per unit area and solid angle. Measure of energy radiated by an object. In general, radiance is a function of viewing angle and spectral wavelength.

Radiation laws.

- **Planck's law** (Max Planck, 1858–1947). $E_{b\lambda} = 2hc^2\lambda^{-5} / [e^{(hc/\lambda kT)} - 1]$, where $E_{b\lambda}$ = monochromatic emissive power (or spectral radiance, or brightness) per unit wavelength interval, λ = wavelength, T = absolute temperature, h = Planck's constant, k = Boltzmann's constant, and c = speed of light.

In words, Planck's law states that the temperature of a blackbody is related to the emitted radiance as a function of the wavelength (or of the frequency). Planck's equation is plotted in Figure 1602 for several temperatures.

Note: The term 'spectral radiance' is commonly used for remote sensing instruments operating at optical wavelengths, while the term 'brightness' is mainly used for the microwave

⁶⁹⁹²⁾ H. J. Buiten, J. Clevers, "Land Observation By Remote Sensing," Gordon and Breach Science Publishers, ISBN 2-88124-936-6, 1993, p. 608

region of the spectrum. Then Planck's law is expressed in units of power density per frequency bandwidth (Hz^{-1}) rather than per unit wavelength interval (m^{-1}). Spectral brightness B_f is related to spectral radiance $E_{b\lambda}$ by: $B_f = E_{b\lambda} |d\lambda/df|$, which results in: $B_f = 2 h f^3 c^{-2} / [e^{(hf/kT)} - 1]$.

In the microwave region ($f < 300 \text{ GHz}$), the term $hf/kT \ll 1$ for the range of physical temperatures commonly encountered in the Earth's surface and atmosphere. Consequently, the spectral brightness equation above reduces to a simpler form: $B_f = 2kT/\lambda^2$ which is known as the Rayleigh–Jeans law, a special case of Planck's blackbody radiation law (see also **brightness temperature**).

- **Wien's displacement law** (Wilhelm Wien, 1864–1928). A law indicating that the wavelength at which the emitted amount of energy by a blackbody is maximal is inversely proportional to the absolute temperature of that body.
- **Kirchhoff's law** (Gustav Robert Kirchhoff, 1824–1887). A law stating that under conditions of thermal equilibrium, the absorption spectrum of an arbitrary body must be equal to its emission spectrum. Kirchhoff's identity: ϵ (emissivity) = α (absorptivity).
- **Lambert's law** (Johann Heinrich Lambert, 1728–1777). A law stating that the radiant intensity (flux per unit solid angle) emitted in any direction from a unit radiating surface varies as the cosine of the angle between the normal to the surface and the direction of radiation. The radiance of a radiating surface is therefore independent of direction. This law is also satisfied (by definition) by the distribution of radiation from a perfectly diffuse radiator.

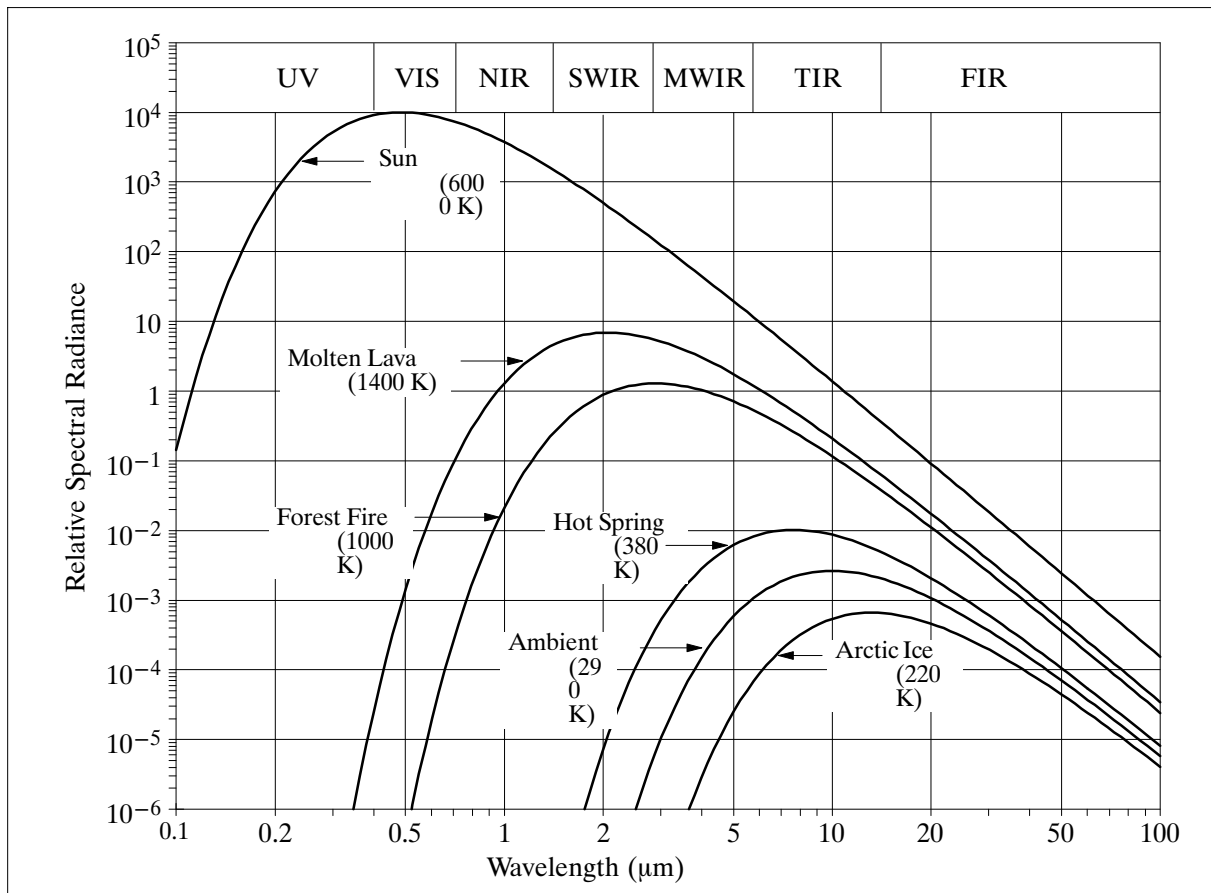


Figure 1602: Hemispherical radiation emitted by objects at typical temperatures

Radiation hardening. Exposed satellite and instrument components, such as detectors, are constantly subjected to space irradiation effects. In particular, long-term exposure may

cause radiation damage to electronic components by altering the properties of a material arising from exposure to ionizing radiation (penetrating radiation), such as X-rays, gamma rays, neutrons, or heavy-particle radiation. With proper hardening processes applied, the components may be turned into radiation-tolerant products.

Radioactivity. Discovered by Antoine-Henri Becquerel (1852–1908), a French physicist, in 1896. He discovered radioactivity completely by accident when he exposed a chunk of uranium to a photographic plate. This opened up a whole new field of research to uncover the source of the mysterious energy. – Radioactivity is an effect/property exhibited by certain types of matter of emitting energy and subatomic particles spontaneously. The emissions of the most common forms of spontaneous radioactive decay are the alpha (α) particle, the beta (β) particle, the gamma (γ) ray, and the neutrino.

Radio astronomy. The first identified astronomical radio source was one discovered serendipitously in the early 1930s when Karl Guthe Jansky, an engineer with Bell Telephone Laboratories (Murray Hill, NJ, USA), was investigating static that interfered with short wave transatlantic voice transmissions. Using a large directional antenna at a frequency of 20.5 MHz, Jansky noticed that his analog pen-and-paper recording system kept recording a repeating signal of unknown origin. This was the discovery of extra-terrestrial radio signals and in fact the start of radio astronomy science. Jansky published his findings in 1933. His pioneering efforts in the field of radio astronomy have been recognized by the naming of the fundamental unit of radio flux density, the Jansky (Jy), after him.

Radio beacon. A type of radio transmitter with wide-angle coverage. It may emit signals continuously or, like the transponder, may respond to input energy before operating. Beacons are used primarily in navigation and radio-detection finding. In meteorology a beacon is used in rawinsonde observations.

Radiodetermination. Refers to the determination of position, velocity and/or other characteristics of an object, or to obtaining information relating to these parameters, by means of the propagation properties of radio waves. The radiodetermination service has two parts to it: the **radionavigation service** and the **radiolocation service**.

1) Radionavigation Systems. Radionavigation is used for the purpose of navigation (aeronautical, maritime, land, and space), including obstruction warning.

– LORAN-C (Long Range Navigation) operates on 100 kHz; it is used in maritime and aeronautical applications (see **LORAN**)

– Omega is a worldwide CW system; it is used for maritime and aeronautical navigation. System operation in the VLF band (9–14 kHz) on four discrete frequencies. (see **OMEGA**)

– VOR/DME (VHF Omnidirectional Range/Distance Measuring Equipment). VOR operates in the 108–118 MHz band, providing azimuth readings to aircraft. DME is collocated with VOR providing distance; it operates in the 960–1215 MHz band.

– TACAN (Tactical Air Navigation) is the US military version of DME. It operates in the 960–1215 MHz band.

– ILS (Instrument Landing System) for precision navigation. ILS consists of a localizer operating in the 108–112 MHz band and a glidescope operating in the 328.6–335.4 MHz band.

– MLS (Microwave Landing System), operating in the 5000–5150 MHz range with associated DME in the 960–1215 MHz range. MLS was initially considered a successor to ILS. It probably may be succeeded by GPS systems.

– GPS (Global Positioning System), a US satellite-based system operating in the 1215–1240 MHz and 1559–1610 MHz bands. GPS was officially integrated into the US

National Airspace System on February 17, 1994. In the future, GPS is expected to replace such systems as Omega, LORAN–C, and perhaps VOR/DME.

- GLONASS (Global Orbiting and Navigation Satellite System), a Russian satellite–based system operating in the 1215–1260 and 1559–1626.5 MHz bands. By the year 2005 the second bandwidth of GLONASS is expected to be the same as that of GPS. There is a major trend towards increased use of the GPS and GLONASS satellite–based system for many navigation applications.

- etc.

2) Radiolocation Systems: The service is used by pulsed and CW radar systems for a number of applications, such as determining precise location, search or surveillance, target tracking, weapons control, ground mapping and target identification, or combinations of these applications. The military is by far the largest user of this service, but there are also a number civil users (NASA, NOAA, CNES, CRC, Russia, etc.

- S&RSAT (Search & Rescue Satellite, CNES/CRC) flown on NOAA–POES satellites. The S&R instruments consist of a 3–band (121.5, 243, and 406.05 MHz) repeater S&RR and a 406.025 MHz processor. The system may receive three types of radiobeacons, namely aviation ELTs (Emergency Locator Transmitter), maritime EPIRBs (Emergency Position Indicating Radio Beacon), and PLBs (Personal Locator Beacon). S&RSAT was declared operational in 1985. The COSPAS–SARSAT agreement was signed in 1988.

- COSPAS (Space System for Search of Vessels in Distress, Russian system).⁶⁹⁹³⁾ The system is flown on Cospas series satellites (named Nadezda) and administered by Russia, US, France, and Canada. Distress alert and location data to RCCs (Rescue Coordination Centers) for 121.5 MHz beacons within the area of COSPAS–S&RSAT ground stations (Local User Terminals – LUTs), and for 406 MHz beacons activated anywhere in the world.

- IVHS (Intelligent Vehicle Highway Systems) or ITS (Intelligent Transport Systems)

- etc.

Radiometer. An instrument for the quantitative measurement of the intensity of electromagnetic radiation in some band of wavelengths in the spectrum. Usually a radiometer is characterized with a prefix, such as IR–radiometer, or microwave–radiometer, to indicate the spectrum to be measured.

Radiometer (absolute cavity radiometer). An instrument based on the measurement of a heat flux by an electrically calibrated transducer. Optical radiation absorbed in a black cavity is substituted by electrical heating during a shaded reference phase. For practical use of the instrument, an electronic circuit keeps the heat flux constant by controlling the power fed to a cavity heater [this is also referred to as ESR (Electrical Substitution Radiometry) – directly relating the optical watt to the electrical watt]. Absolute cavity radiometers are used to measure the Solar Constant or TSI (Total Solar Irradiance).^{6994) 6995)}

The basic theory of ESR detectors is based on the measurement of heat flux. Two identical sensors, one active and one used as a thermal reference, are connected so that they are in the same environment and at the same temperature. Joule heat is supplied to each sensor by an “actively controlled” resistive heater circuit. The sensors have very high absorptance in order to efficiently collect radiation, so that nearly all photon energy incident on the detector is converted into heat. As radiation falls on the active sensor, a corresponding amount of Joule heat to that sensor must be reduced in order to maintain the heat flux balance. This change in Joule heat to the active sensor is equivalent to the amount of radiation incident upon it.

⁶⁹⁹³⁾ COSPAS–S&RSAT homepage, <http://www.cospas-sarsat.org/>

⁶⁹⁹⁴⁾ <http://physics.nist.gov/Pubs/TN1421/electrical.html>

⁶⁹⁹⁵⁾ <http://lasp.colorado.edu/sorce/>

Note: electrical substitution radiometry at cryogenic temperatures is also the basis of detector calibrations in which a detector's response to optical flux is measured as a function of wavelength.

Radiometric resolution. See **resolution**.

Radiation dose: The “rad” is a unit used to measure a quantity called absorbed radiation dose. This relates to the amount of energy actually absorbed in some material, and is used for any type of radiation and any material. The unit of a rad is defined in Gy = “Gray”. Louis Harold Gray (1905–1965) was a British physicist and president of BIR (British Institute of Radiology). The “gray” was defined in 1975. ⁶⁹⁹⁶⁾

The gray is a SI unit used to measure a quantity called absorbed dose. This relates to the amount of energy actually absorbed in some material, and is used for any type of radiation and any material. One gray is equal to one joule of energy deposited in one kg of a material (1 Gray (or (gray) = 1 J/kg = 1 m² S⁻²). Note: In the SI system, the rad is replaced by the gray; 1 krad = 10 gray.

In the the context of radiation shielding, the term “rad” (or Rad) is also used for energy accumulated in matter (dosimetry for the energy absorbed per unit mass of material, usually by ionization processes). A rad is the amount of particle radiation that deposits 10⁻² J/kg of target material. Besides the “rad” is the “**Gray**.” 1 rad = 1/100 Gray.

The space radiation dose to which spacecraft in LEO (Low Earth Orbit) altitudes (400 km to 1000 km) are subjected, is dominated by contributions from geomagnetically trapped protons (typical energy range of 0.1 MeV to > 100 MeV) and electrons (typical energy range of 0.1 MeV to 6.0 MeV).

Radiosonde. A balloon–borne instrument which measures (by means of transducers) and transmits meteorological data (temperature, pressure, humidity). Various types of transmission schemes exist.

- **Rawinsonde** (Radio–Wind–Sonde). A balloon–borne instrument tracked by radar or radio direction–finder and operating on the same principle as a radiosonde, but with the additional capability to measure wind speed and direction.
- **Dropsonde.** A radiosonde or a rawinsonde dropped by parachute from an aircraft for the purpose of obtaining soundings of the atmosphere below. The radio signals of the dropsonde/rawinsonde are tracked for data evaluation.

Radio occultation principle. Fundamentally, the technique relies on the simple fact that a planet's atmosphere acts much like a spherical lens, bending and slowing propagation of microwave signals passing through it tangent to the surface. The lens effect results from decreasing atmospheric density with altitude. If the positions of transmitting and receiving satellites are precisely known, then the atmospheric delay can be measured precisely, the time derivative of which (Doppler) can be inverted to give atmospheric density versus altitude.

Advanced GPS receivers also enable determination of line–integrated electron density between the spacecraft and a particular GPS satellite. This is the basis for GPS radio occultation tomography; as a GPS satellite sets behind a LEO satellite, line–integrated electron data are recorded at different times, which results in density data along different paths through the ionosphere. Tomographic reconstruction can provide density vs. altitude data for a vertical slice through the atmosphere. It requires a moderate gain GPS antenna, and 3–axis stabilization to point that antenna in the anti–flight direction.

See also **Limb/Occultation sounding** and **Occultation**. – Note: The radio occultation technique was first developed (in the 1970s) at Stanford University Center for Radar Astronomy

⁶⁹⁹⁶⁾ http://en.wikipedia.org/wiki/Gray_%28unit%29

and at NASA/JPL for the study of solar system planetary atmospheres (Venus, Mars, Jupiter, Saturn, Uranus and Neptune).

Raman spectroscopy. ⁶⁹⁹⁷⁾ A technique to investigate molecular properties using scattered light resulting from photon–molecule collisions. When a monochromatic light beam is incident on systems such as transparent gases, liquids, or solids, most of it is transmitted without change. However, a very small portion of the incident light is scattered. Although most of the scattered light has the same wavelength as the incident radiation, a small part of it has different wavelengths. The scattering of light at different wavelengths is called **Raman scattering** (Indian scientist Sir C. V. Raman, who, with K. S. Krishnan, first reported the phenomenon in 1928). The physical origin of Raman scattering lies in inelastic collisions between the molecules composing the system (e.g. the liquid) and photons, the particles composing the light beam. ‘Inelastic collision’ means that there is an exchange of energy between the photon molecule with a consequent change in energy, and hence wavelength, of the photon.

Range. The distance between two objects, usually between an observation point and a target (object under observation). Slant range: same as range – the line–of–sight distance between two objects.

Ranging is the process of accurately determining the distance between a spacecraft and a ground antenna as a function of time, by measuring the delay for an electromagnetic signal traveling to and returning from the spacecraft. Doppler is due to the rate of change of range, or velocity, and special care must be given in the design of a ranging system to account for the timing effects of forward and return Doppler shifts. On the other hand, Doppler is typically relatively constant over a ranging track, and hence the ranging problem can be reduced from the estimation of one time–varying range parameter to the estimation of two time–invariant parameters, namely, range and Doppler at a specific time.

Range direction. Observation of an instrument in the cross–track direction (normal to the subsatellite track). See also **azimuth direction**.

Range error. The (small) error in radar range measurement caused by the propagation of radio energy through a nonhomogeneous atmosphere. This error is due to the fact that the velocity of radio–wave propagation varies with the index of refraction, and that ray travel is not in straight lines through actual atmospheres (see also **Atmospheric refraction**).

Range resolution. Resolution characteristic of the range dimension, usually applied to the image domain, either in the slant range plane or in the ground range plane. Range resolution is fundamentally defined by the system bandwidth in the range channel. See also **SAR**.

Raster image. Refers to a matrix of row and column data points. Each data point is a pixel.

Rayleigh criterion. The Rayleigh criterion is the generally accepted criterion for the minimum resolvable detail – the imaging process is said to be diffraction–limited when the first diffraction minimum of the image of one source point coincides with the maximum of another.

The diffraction limit is the ultimate angular resolution limit imposed by the laws of optics and is equal to the ratio of the observing wavelength to the telescope diameter.

The angular resolving power of any optical system is diffraction limited by its finite aperture. The image of a point source created by a system with a circular aperture shows this diffraction as a circular Airy pattern. The Rayleigh criterion for the resolution of two adjacent Airy patterns is that the maximum of one pattern falls on the first minimum of the other. The angular resolving power thus increases with the diameter of the aperture. The ultimate limit to resolution is set by the relationship between the size of the entrance aperture D and the wavelength λ of the radiation used by:

⁶⁹⁹⁷⁾ Encyclopedia of Physical Science and Technology, Academic Press, 1987

Angular resolving power (or resolution) $\alpha = 1.22 \lambda/D$ where the angle α is given in radians (note: 1 arcsec = 4.848137×10^{-6} radians). In the above equation, D is the diameter of the aperture and λ is the wavelength of the radiation under consideration. The 1.22 factor arises from the circular aperture. An inspection of the equation shows that:

- 1) For optical imagery (say, of 0.4 μm wavelength) with a resolution (or beamwidth) of 1 arcsecond, it is possible of using a 10 cm (diameter) perfect telescope.
- 2) For microwave imagery (say, of 10 cm wavelength), a resolution of 1 arcsecond would require a telescope (or antenna) aperture diameter of 250 m.

Hence, a practicable solution can only be obtained with the introduction of “**phased arrays.**” Phased arrays get around the beamwidth limit (i.e., Rayleigh criterion) by using several small apertures (linked together) to achieve the same result as one large aperture. Phased arrays synthesize larger apertures from an array of elements.

Resolving power in astronomy applications: The spectral resolution or resolving power (R) of a spectrograph is a measure of its power to resolve features in the electromagnetic spectrum. It is usually defined by: $R = \lambda/\Delta\lambda$, where $\Delta\lambda$ is the smallest difference in wavelengths that can be distinguished, at a wavelength of λ . For example: $R=3000$ means that for a wavelength of 1000 nm (or 1 μm), features of 0.33 nm ($\Delta\lambda$) apart can be distinguished in the spectrograph.

The Rayleigh spatial resolution criteria is the distance at which two targets being measured simultaneously can be resolved at their half–power points.

Rayleigh scattering. Scattering by particles small in size compared with the wavelengths being scattered by the blue light (UV) of the atmosphere (e.g., the blue color of the sky and ocean is caused by Rayleigh scattering of the air and water molecules respectively). Rayleigh scattering is also caused by density fluctuations in atmospheric gases (it increases toward the shorter wavelengths proportional to λ^{-4} where λ is the wavelength). In a sensor energy balance, Rayleigh scattering adds to the radiation received by a sensor; this is most pronounced at shorter wavelengths.

Reaction/momentum wheels. These are actuators (flywheels) which may be used for three–axis reaction control or momentum bias applications. By adding or removing energy from the flywheel, torque is applied to a single axis of the S/C, causing it to rotate (reaction). By maintaining flywheel rotation (momentum), a single axis of the spacecraft is stabilized. Such an assembly provides a reliable source of reaction torque and angular momentum storage for attitude control of medium to large spacecraft. Accelerating or decelerating a flywheel with an integral motor provides a means of controlled momentum exchange with the spacecraft platforms, which is advantageous for a variety of attitude control schemes.

Real–Time Kinematic (RTK). Refers to a DGPS process where carrier–phase corrections are transmitted in real–time from a reference receiver at a known location to one or more remote “rover” receivers. RTK has become a preferred method for surveying applications since it provides real–time positions with high accuracy.

Rectenna (Rectifying antenna). A rectenna is a combined term of a rectifier and antenna – converting RF power to DC power, a useful feature in terms of energy recycling. A rectenna absorbs the microwave beam and simultaneously converts it to DC power. The converted power may be used as a battery–free application and an efficient power management scheme. An example of a rectenna application might be the receiving antenna in a WPT (Wireless Power Transmission) system. A rectenna comprises a mesh of dipoles and diodes for absorbing microwave energy from a transmitter and converting it into electric power.

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Reflectance. Refers to the fraction of the total radiant flux incident upon a surface that is reflected (a unit-less number between 0 and 1); it varies according to the wavelength distribution of the incident radiation as well as with the angle incidence and reflection.

Reflection. The scattering of electromagnetic radiation by an object. Diffuse reflection causes the radiance of the reflected radiation to be equal in all directions (e.g. reflection from a rough surface). Specular reflection has a direction of preference (e.g. the reflection of a smooth surface). The use of the terms ‘smooth’ and ‘rough’ is independent of wavelength.

Reflectivity. A property of illuminated objects to reradiate a portion of the incident energy. For SARs, backscatter is the observable portion of the energy reflected. Backscatter, in general, is increased by greater surface roughness.

Refraction. A process by which the direction of energy propagation is changed due to a change in density within the propagating medium (smooth bending), or due to a discontinuity between two media (abrupt bending). – Atmospheric optical phenomena are produced by continuous and discontinuous refraction: scintillation, mirages, astronomical refraction, anomalous propagation of radio waves and the bending of sound waves are examples of refraction within a single medium.

Refractive index (in a medium). The inverse ratio of the wavelength (or velocity) of electromagnetic radiation in the medium to that in vacuum. A measure of the amount of refraction (a property of the dielectric constant). See also **Atmospheric refraction** and **Occultation**.

Registration. Geometric rearrangement of the pixels in an image for image matching by superposition – often to the reference geometry of a map (geocoding). Image registration is the process of matching (overlying) two or more images so that corresponding coordinate points in the images correspond to the same physical region of the scene being imaged. The technique is used for a number of applications:⁷⁰⁰⁰⁾

- Integration of information taken from different sensors (sensor or image fusion)
- Analysis of changes in images taken at different times (temporal registration and change detection).

In a wider sense image registration tries to combine image data with different spatial, spectral and radiometric characteristics to improve the information extraction process from available imagery. Typical registration processing steps are: feature identification, feature matching, spatial transformation, and interpolation.

Relative aperture. For a photographic or telescopic lens system, the ratio of the equivalent focal length to the diameter of the entrance slit. It is expressed as $f/45$ or $f/5.6$, and is also called the ‘f-number,’ speed of lens, or the ‘focal ratio.’

Renewable energy. Refers to energy technologies that generate electricity, fuels, and/or heat through the use of resources which are continually replenished, such as sunlight (photovoltaic), heat from the sun (solar thermal), wind, naturally occurring underground steam and heat (geothermal), plant and animal waste (biomass), and water (hydropower).

Repeat period (or cycle). Time interval between successive satellite observations of the same area of the Earth’s surface.

6998) S.–J. Lim, T. Itoh, “A 60 GHz Rectenna and Power Combining Technique,” Proceedings of the 4th ESA Workshop on Millimeter–Wave Technology and Applications,” WPP–258, Feb. 15–17, 2006, Espoo, Finland

6999) Y.–H. Suh, K. Chang, “A high–efficiency dual–frequency rectenna for 2.45 and 5.8 GHz wireless power transmission,” IEEE Transactions on Microwave Theory and Techniques, Vol. 50, No 7, July 2002, pp. 1784–1789

7000) L. M. G. Fonseca, B. S. Manjunath, “Registration Techniques for Multisensor Remotely Sensed Imagery,” PE&RS, Vol. LXII, No. 9, Sept. 1996, pp. 1049–1056

Resampling. The rearrangement of the resolution cells of each scanned line of an image into geometrically equal terrain elements (geometric rearrangement) by creating artificial pixels whose spectral radiation data are computed from the original values proportional to the area coverage by the new pixels with respect to the resolution cells. In general a resampling process follows after a geometric rearrangement (registration) of the pixels because of the matching of two different images of the same region by means of a mathematical transformation. The resampling then involves the assignment of artificial pixel values to the newly formed pixels according to the selected sampling algorithm.

Resolution. A term defining the smallest discernable physical unit of an observed signal by a sensor (measurement). It can be divided into four types: **spatial, spectral, radiometric, and temporal resolution.**

- Spatial or geometric resolution defines the minimum (spatial) separation between two measurements in order for a sensor to be able to discriminate between them. Spatial resolution defines the size of an image resolution cell in the target area, or the size of pixels. The spatial resolving power is determined by the aperture dimensions of a lens or the antenna of a sensor. – Some spatial connotations are: GSD, IFOV, FOV, look angle of the sensor, shape and size of the object, position, site, distribution, texture.
- Spectral resolution refers to the resolving power of a system in terms of wavelength (or wavenumber) or frequency. Spectral resolution is achieved by decomposing the radiance received in each spatial pixel into a number of wavebands. The wavebands may vary in resolution, and may be overlapping, contiguous, or disparate, depending upon the design of the sensor. A color image, consisting of red, green, and blue bands, is a familiar example of a spectral sampling in which the wavebands (spectral channels) are non-overlapping and relatively broad.
- Radiometric resolution refers to the resolving power of a system in terms of the signal energy [detection of energy differences (reflection and emission) in terms of temperature, intensity and power]. The radiometric resolution is the Noise Equivalent Delta Radiance (NE Δ R), or the Noise Equivalent Delta Temperature (NE Δ T), depending on the spectral measurement range. This can be defined as the minimum change in reflectance (or temperature) that can be detected by a sensor. The value depends on a number of parameters, such as SNR, the saturation radiance setting, and the number of quantization bits. The important parameter of an instrument is the SNR. The resolution capability of an instrument in terms of quantization does not necessarily give an idea of its precision or accuracy with which it can measure. Nevertheless, a higher number of bits increases the dynamic range of the instrument, permitting the measurement of very variable targets, without a gain change. See also **Full Width Half Maximum.**
- Temporal resolution concerns the time lapse between two successive images of the same target area (at the same viewing angle and by the same spaceborne LEO sensor, at the next revisit time; in GEO the next image of the same target represents the temporal resolution). Various phenomena, which may be observed from space, have different temporal and spatial scale requirements. For example, severe storms evolve quickly, and observations every 15 minutes or less may be required. On the other hand, ice sheets evolve slowly and thus may be observed less continuously. Similar arguments can be made for spatial requirements. Obviously, a sensor in GEO is capable providing far better temporal data of a target area than a sensor on a LEO spacecraft. However, the sensor on the LEO S/C has the edge in offering a far better spatial resolution than its counterpart in GEO. This is simply dictated by the orbital geometry with a distance ratio of 1:45 (LEO/GEO – or 800:36,000 km) in favor of LEO. Hence, a LEO constellation of S/C represents a fairly good compromise to achieve a fairly high temporal resolution combined with a high spatial resolution.

Retrograde motion: Refers to motions of a celestial body relative to a gravitationally central object. Retrograde motion is in the direction opposite to the movement of something else,

and is the contrary of direct or “prograde” motion. The idea of retrograde or prograde motion is useful in three contexts:

- for describing the orbits of celestial bodies
- for describing the rotations of celestial bodies (spin motion)
- for explaining the backtracking by planets which is visible to observers on Earth.

A retrograde Earth orbit of a spacecraft is an orbit, where the satellite travels in an East to West direction instead of the common (prograde) West to East orbit. All sun–synchronous orbits of LEO spacecraft are of the type retrograde. – In retrograde orbits, the projection of the satellite’s position onto the equatorial plane revolves in the direction opposite to Earth’s rotation (i.e. a retrograde orbit has a westward motion or precession on consecutive orbits).

In our Solar system, mostly everything rotates in the same sense (as the central body): all major planets orbit the Sun counterclockwise as seen from the pole star (Polaris). Most planets spin in the same sense, including Earth. The same happens with the orbital motions of the Moon, Mars’ moons, and the biggest moons of Jupiter and Saturn around their planets. All these motions are called “prograde.” However, the spin motion of Venus and Uranus is clockwise, so they have a retrograde rotation.

So far, all exoplanets (extrasolar planets) discovered (on the order of 400 in the spring of 2010) are also orbiting their central star in a prograde fashion. However, at the annual RAS NAM 2010 (Royal Astronomical Society National Astronomy Meeting) in Glasgow, UK (April 12–16, 2010), it was announced that several extrasolar planets have been discovered to have retrograde orbits – i.e. they are orbiting their host star in the opposite direction as their host star rotates.⁷⁰⁰¹⁾

This new discovery challenges accepted ideas of how planets form. Planets are thought to form in the disc of gas and dust encircling a young star. This proto–planetary disc rotates in the same direction as the star itself, and up to now it was expected that planets that form from the disc would all orbit in more or less the same plane, and that they would move along their orbits in the same direction as the star’s rotation. This is the case for the planets in the Solar System.– The new findings suggest that astronomers have to revise some aspects of planet formation.⁷⁰⁰²⁾

Rheology. A science dealing with the deformation and flow of matter.

Revisit period. Refers to the length of time it takes for a satellite to complete one entire orbit cycle. The revisit period of a satellite sensor is usually several days. Therefore the absolute temporal resolution of a remote sensing system to image the exact same area at the same viewing angle a second time is equal to this period.

S/A (Signal–to–Ambiguity ratio). In SAR instruments the ratio of the receiving power of the signal scattered and reflected from the observed (target) area to the power leaking into the observation area from the non–observed area.

Sampling. In general, any process of converting an image into a discrete set of numbers. Normally, the numbers represent the image values at a grid of points (or average values over a small neighborhood of points). According to the sampling theorem, if the grid spacing is d , an exact reconstruction of all periodic (sinusoidal) components of the image can be made that have period $2d$ or greater (or, equivalently, “spatial frequency” $1/2 d$ or fewer cycles per unit length).

7001) “Turning Planetary Theory Upside Down: Nine New Exoplanets Found, Some With Retrograde Orbits,” Science Daily, April 13, 2010, URL: <http://www.sciencedaily.com/releases/2010/04/100413071749.htm>

7002) “Retrograde Planets Test Formation Views,” Space News, April 19, 2010, p. 11

SAR (Synthetic Aperture Radar), see SAR under **Radar**.

SAR imaging modes: In airborne and spaceborne SAR observations there are generally three common imaging modes for data collection based on active phased array technology of the antenna; the modes are referred to as: stripmap, spotlight, and ScanSAR

- **Stripmap:** The antenna pointing is fixed relative to the flight line (usually normal to the flight line). The result is a moving antenna footprint that sweeps along a strip of terrain parallel to the path motion. The stripmap mode is normally used for the mapping of large areas (usually with coarse–resolution data). Stripmap imaging employs the same incidence angles. – In wide–swath stripmap mode imaging, the physical length of the antenna required increases linearly with the corresponding azimuth resolution cell size.

- **Spotlight** (also referred to as spotSAR): The sensor steers its antenna beam to continuously illuminate a specific (predetermined) spot or terrain patch being imaged while the aircraft/spacecraft flies by in a straight line. The spotlight mode is a practical choice when the mission objective is to collect fine–resolution data from one or more localized areas. – The following attributes distinguish spotlight and stripmap modes. First, the spotlight mode offers finer azimuth resolution than that achievable in stripmap mode using the same physical antenna. Second, spotlight imagery provides the possibility of imaging a scene at multiple viewing angles during a single pass.

Note: While the operation in spotlight mode allows for improved azimuth resolution by decreasing artificially the ground–track velocity. This has to be payed for with along–track gaps between consecutive scenes.

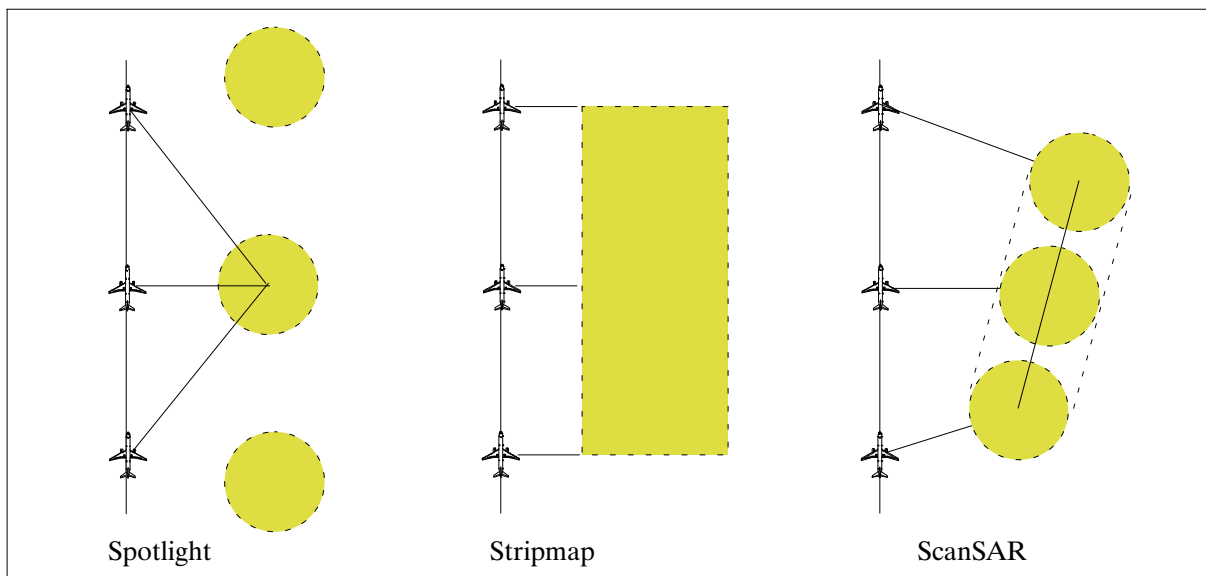


Figure 1603: Illustration of common SAR imaging modes

- **ScanSAR:** The sensor steers the antenna beam in cross–track to illuminate a strip of terrain at any angle to the path of aircraft/spacecraft motion (the stripmap and spotlight modes are becoming special cases of the ScanSAR mode). The interpretation of ScanSAR signatures is generally more complicated than data obtained in stripmap mode, due to strongly varying incidence angles. ScanSAR modes allow to increase the total swath width without the need of extending the antenna length. Multi phase center systems allow to generate a number of differently shaped radar beams – e.g. for wide swath ScanSAR modes. However, the wider swath in ScanSAR can only be obtained at the cost of a coarser spatial resolution.

SAR range ambiguity reduction. The technique involves encoding of the transmitted radar pulses (the pulses are modulated with different signal structures). The coding (tagging) of the transmit pulses allows the range ambiguities to be filtered out.

Satellite surface charging. All bodies which are placed in a plasma in thermal equilibrium acquire a negative electrostatic charge. The negative potential depends on the plasma temperature. At altitudes of 300 to 500 km, the average kinetic energy of the plasma is low (< 1 eV), hence, satellites become only weakly charged. At high altitudes (geostationary orbit and further out) the kinetic energy of the plasma is considerably larger (the plasma is referred to as ‘hot’), hence, satellites acquire a high potential with respect to it (in the order of several keV). The electrostatic charge on satellite surfaces can pose a hazard, in particular when differential charging is leading to potential gradients. In some cases this potential build-up causes discharge arcing. Electrostatic charging by the natural space radiation environment is an accepted source of many anomalies of S/C electronics.

Satellite classes. Satellites may be categorized by a number of different criteria such as mass (large, small, mini, micro), or functions and services (EO, communication, space science, data collection, navigation, orbit, etc.), or by other criteria. Within the last years advances in digital microelectronics resulted in achieving sophisticated functions within ever smaller constraints of mass, volume, and power. This in turn brought about a miniaturization trend in platforms and instruments, and a demand for low-cost projects. The following classification has become widely accepted: ⁷⁰⁰³⁾

Satellite Class		Mass
Large satellite (observatory, etc.)		> 1000 kg
Minisatellite	Small Satellite Class (or LightSats)	$100 - 1000$ kg
Microsatellite		$10 - 100$ kg
Nanosatellite		$1 - 10$ kg
Picosatellite		$0.1 - 1$ kg
Femtosatellite	Satellite-on-a-chip (SpaceChip, PCBSat)	$1 - 100$ g

Table 974: Satellite classification by mass criterion

Satellite Laser Ranging (SLR). Very precise range measurements from ground reference stations to geodynamic satellites (like Lageos, Starlette, Stella, Geo-1K, Etalon, EGS, etc.). The SLR technique employs short pulse lasers from the ground to retroreflectors on satellites. While the above listed geodynamic satellites are dense reflector-covered spheres (dedicated to laser ranging), there may also be configurations where a satellite flies a retroreflector arrangement as an experiment. The quantity of interest is time-of-light (round trip) corrected for ranging system internal delay (calibration), atmospheric refraction (delay), retroreflector offset to the S/C center-of-mass, and network epoch synchronization. The short wavelengths of visible light result in a single-shot precision of about 2 cm. SLR techniques are a strong contributor to advances in precision orbit determination. The applications of SLR data from geodetic satellites includes detection and monitoring of tectonic plate motion, crustal deformation, earth rotation, and polar motion; modeling of the spatial and temporal variations of the earth’s gravitation field; determination of basin-scale ocean tides; monitoring of millimeter-level variations in the location of the center of mass of the total earth system (solid earth-atmosphere-oceans); establishment and maintenance of the International Terrestrial Reference System (ITRS); detection and monitoring of post-glacial rebound and subsidence; monitoring the response of the atmosphere to seasonal variations in solar heating.

The temporal variations of the Earth’s gravity field provide information about the mass transport in the system Earth, i.e., about the relations between the mass redistribution in the atmosphere, oceans, land hydrology, and ice sheets. Satellite Laser Ranging (SLR) mea-

⁷⁰⁰³⁾ D. J. Barnhart, T. Vladimirova, M. Baker, M. N. Sweeting, “A Low-Cost Femtosatellite to enable Distributed Space Missions,” Proceedings of the 57th IAC/IAF/IAA (International Astronautical Congress), Valencia, Spain, Oct. 2–6, 2006, IAC-06–B5.6.06

measurements to geodetic satellites have been delivering valuable information on the lowest-degree coefficients of the Earth's gravity field since 1975 and 1976, i.e., since the two SLR-dedicated spherical satellites Starlette and LAGEOS-1 were launched, respectively. Today, the GRACE (Gravity Recovery And Climate Experiment) mission is the key source of information for the temporal gravity field variations. The tandem GRACE-A/B satellites allow defining the mass variations with high spatial resolution and accuracy. The lowest-degree coefficients of the gravity field, however, are still better defined by the geodetic SLR satellites because the K-band GRACE observations are nearly insensitive to the geocenter variations due to their interferometric measurement type. This leads to a degraded C20 coefficient (i.e. the Earth's dynamical flattening) due to long-period signals such as the S2 and S1 tidal aliases with GRACE orbits. Therefore, SLR to geodetic satellites is the best technique to determine C20.⁷⁰⁰⁴⁾

Satellite structure: Basic Elements. Satellite structures must survive launch, meet out-gassing and other mission-specific requirements, provide stiffness, dimensional stability and thermal control, and allow equipment mounting and containment. Remote sensing satellites are comprised of a number of subsystems. The actual number of subsystems depends on the complexity of the mission and the overall design of the spacecraft. The trend is in the direction of standardized modular subsystems with high functional autonomy.

- **Satellite structure.** Refers to the basic platform or “bus” (design, body, shape, etc.) and subsystem accommodation.
- **Thermal control subsystem (passive and/or active).** Orbital temperatures may vary considerably due to varying solar irradiation. The subsystem provides the proper thermal environment for a number of subsystems (in particular electronic or optical equipment). Thermal balance may be maintained by using an exterior finish that absorbs or emits radiation; this is referred to as a ‘passive system.’ An active system may use louvers to achieve a required environment
- **G&C (Guidance and Control) subsystem.** G&C is responsible for all functionality associated with spacecraft attitude (sensing and control), a basis for proper S/C pointing. G&C is sometimes simply referred to as ‘attitude control.’ See also **Spacecraft stabilization.**
- **Power subsystem.** The subsystem is responsible for providing continuous power for all subsystems throughout the mission. The two most common power sources are solar cells and high performance batteries. The solar energy may vary depending on satellite orbit (due to sun eclipses or varying sun elevation angles). Batteries (such as NiCd or NiH₂) are used as a supplemental onboard energy source.
- **Power distribution.** Refers to the spacecraft cabling system to all subsystems. Sometimes this electrical distribution function is integrated into the spacecraft bus.
- **Antenna subsystem.** The subsystem is responsible for receiving and transmitting telecommunication signals between ground and spacecraft (maybe in several bands).
- **C&DH (Command and Data Handling) subsystem.** The subsystem is responsible for command processing, data management, health and status management, telecommunications management, and power management.
- **Spacecraft bus.** A shared communications medium for all subsystems (like serial busses or parallel backplane busses). This requires a common interface definition. Some S/C series of agencies or companies offer standardized systems capable of accommodating a variety of payloads and subsystems. Newer designs consider the S/C bus as the physical structure for distribution of all onboard services (data, electricity, etc.) to the payload along with the integration of all service subsystems (attitude and control, timing, thermal control, etc.).

⁷⁰⁰⁴⁾ “Temporal Earth’s gravity field variations from SLR observations,” University of Bern, URL: http://www.aiub.unibe.ch/research/slr_data_analysis/gravity_field_determination/index_eng.html

- **Spacecraft computer.** Depending on spacecraft complexity there may be a S/C computer and/or subsystem computers.
- **Data recorder.** Responsible for recording data streams during non–contact periods of the S/C. This may be an independent device (high volume and high data rate) or solid state memory storage in a S/C computer.
- **Payload instruments.** A suite of sensors performing assigned observations. Such instruments may be imagers, sounders, radiometers, etc.
- **Timing subsystem.** Responsible for giving a uniform time stamp to all required interfaces.
- **GPS receiver.** Ever more satellites are carrying such a system for orbit determination.

Scales (macro–, meso–, and microscales). See observational scales in modeling chapter Q.11 on page 3584.

Scanning. The sweep of a mirror, prism, antenna, or other element across a track (normal to the direction of flight); the footprint may be a straight line, a circle or any other shape. In general, the process of scanning is a programmed motion that can be used either for measuring angular location of a target, or it can be used to extend the angular range of an antenna beam. There are two basic ways of classifying scanning methods:

- From the viewpoint of the type of beam motion introduced to scan a volume, the methods are described as: raster scan, helical scan, etc.
- From the viewpoint of beam steering, the methods are described as mechanical, electromechanical, or as electronic.

Parameter	Object plane scanning technique	Image plane scanning technique
Scanning mechanism	Mirror for rotating and/or tilting	No mechanism
Width of scanning	Wide	Narrow
IFOV (Instantaneous Field of View)	Narrow	Wide
Aperture optics	Large	Small
Optical system	Catoptic system	Dioptric/catoptic system
Spectral range	VIS – TIR	VIS – VNIR
Number of optical detectors	Few	Many (area array)
SNR (Signal–to–Noise–Ratio)	Low	High
Size and mass	Large and heavy	Small and light

Table 975: Comparison of scanning techniques for imaging spectrometers

Scanner. An instrument that scans and by this means produces an image. A two–dimensional image is generated by the forward motion of the satellite platform. The addition of single pixels in combination with cross–track scanning (whiskbroom) or of a cross–track line of pixels (CCD line array) are the basic elements of such an image. Common scanner types are: a) whiskbroom (cross–track multispectral imaging with discrete detectors), b) pushbroom (cross–track multispectral scanner with CCD line arrays), c) hyperspectral scanning with area arrays (see chapter Q.3).

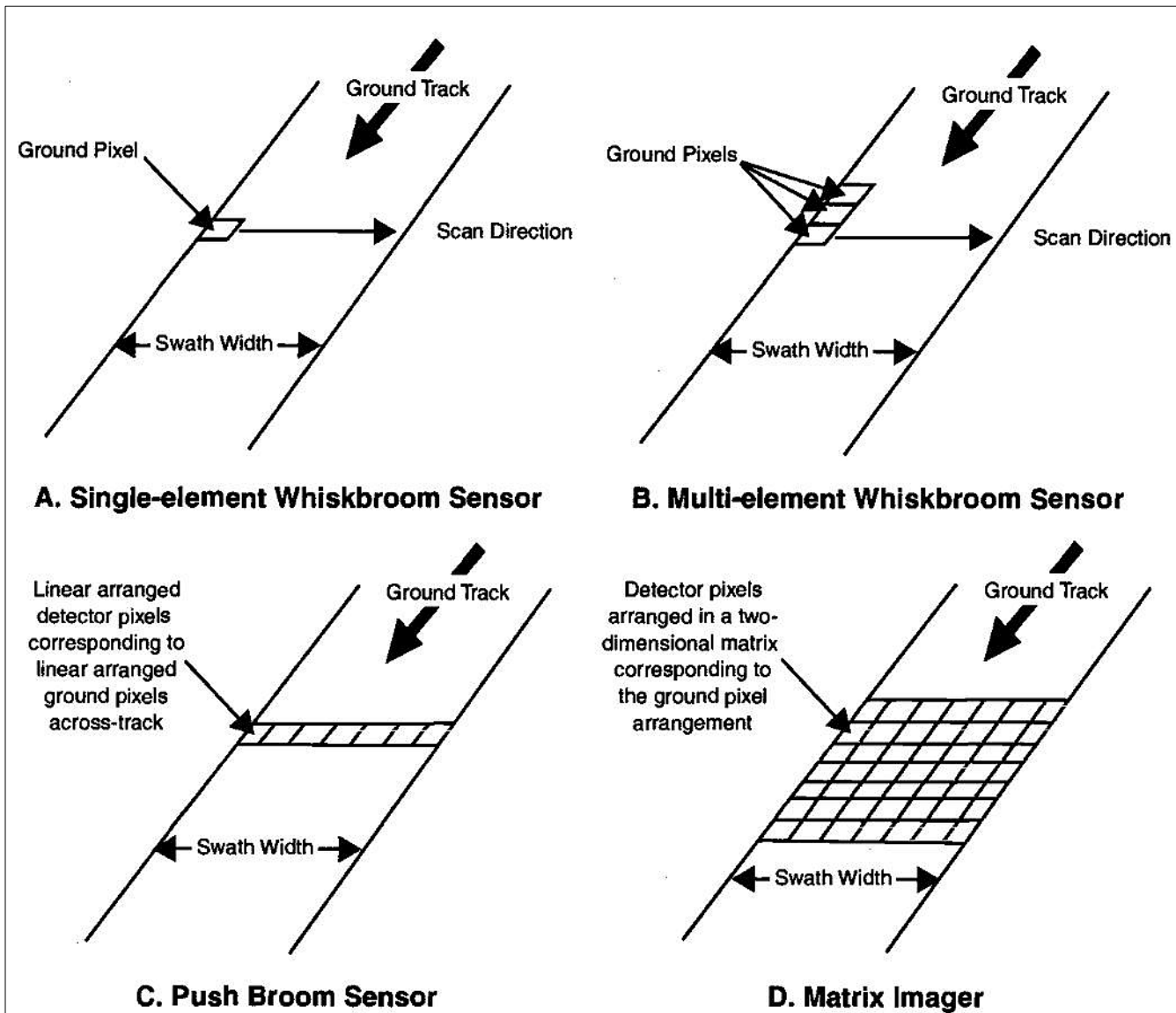


Figure 1604: Overview of scanning techniques (image credit: ISS, University of Stuttgart)

ScanSAR. A SAR imaging technique permitting acquisition of a larger observation swath than what would normally be possible due to range–Doppler ambiguity limitations, but at the expense of reduced resolution. The technique, based on phased array antenna technology with a rapid electronic steering capability of the elevation beam pattern, permits a high degree of flexibility in ground observation coverage. The principle of this mode of operation is to illuminate an area on the ground long enough to acquire imagery (synthetic aperture) for the desired resolution and then move the illuminated beam to a different area across the swath to increase coverage. Hence, the operational time of the SAR beam pattern is shared between two or more subswaths in such a way as to obtain full image coverage of each. However, a contiguous subswath coverage implies shorter integration times for each footprint, resulting in shorter integration times – consequently, the resolution of the resulting image is degraded.

The ScanSAR technique may also serve to cover an event of interest, positioned close–by but still outside the normal coverage of the current orbit. The required beam pointing for such an event can be done on command with the phased array antenna.

Scattering. Light absorbed and subsequently re–emitted by particles suspended in a medium in all directions at about the same frequency. In scattering no energy transformation results, there is only a change in the spatial distribution of the radiation. – Scattering varies as a function of the ratio of the particle diameter to the wavelength of the radiation. When

this ratio is less than about one–tenth, **Rayleigh scattering** occurs in which the scattering coefficient varies inversely as the fourth power of the wavelength. At larger values of the ratio of particle diameter to wavelength, scattering varies in a complex fashion described by the Mie theory (particle size is comparable with the wavelength dimension). At a ratio of the order of ten, the laws of geometric optics begin to apply and this serves to mark the somewhat diffuse upper boundary of the realm of scattering (where diffraction begins). Primary scattering of the Rayleigh type, largely by air molecules, is responsible for the blue sky and the polarization of the sky's light. On the other hand, **Mie scattering** occurs by the interaction of radiation (light) with aerosols or cloud particles.

Scattering matrix. An array of complex numbers that describes the transformation of the polarization of a wave incident upon a reflective medium to the polarization of the backscattered wave. See also **radar polarimeter** under **radar**.

Scatterometer types. There are two basic designs of scatterometers: the traditional fan–beam Doppler scatterometer (examples: NSCAT, AMI–SCAT), and the scanning pencil–beam scatterometer. The fan–beam Doppler scatterometer requires multiple antennas to achieve the target illumination pattern (sticklike antennas are used to broadcast long, narrow radar footprints). The FOV requirements of the antennas are very strict making fan–beam scatterometers very difficult to accommodate on S/C. – The design of the newer scanning pencil–beam instrument is more compact; they offer long dwell times which result in better SNRs. SeaWinds on ADEOS–II will be a scanning pencil–beam scatterometer.⁷⁰⁰⁵⁾

Schottky diode (named after Walter H. Schottky). A diode that has a metal–semiconductor contact (e.g., an Al layer in intimate contact with an n–type silicon substrate). The Schottky diode is electrically similar to a p–n junction, though the current flow in the diode is due primarily to carriers having an inherently fast response. It is used for high–frequency, low–noise mixer and switching circuits.

Scintillation. Variations in the brightness of starlight (i.e. ‘twinkling’) caused by turbulent strata very high in the Earth's atmosphere (ionosphere). Also, the emission of sparks or flashes. In general, scintillation refers to the fluctuation of amplitude and/or phase of a signal caused by the irregular structure of the propagating medium.

Scintillation counter. A device that uses a photomultiplier tube to detect or count charged particles (which produce scintillations of radiation when they impact upon phosphor) or γ –rays.

Sea Surface Salinity (SSS).⁷⁰⁰⁶⁾ SSS is an important variable in ocean and climate dynamics. In polar oceans, SSS intrusions with a low salinity influence the deep thermohaline circulation and the meridional heat transport. Variations in salinity also influence the oceans near surface dynamics in the tropics where rainfall modifies the buoyancy of the surface layer and the tropical ocean–atmosphere heat fluxes (warm surface pool dynamics). – The physical basis for SSS remote sensing is the microwave brightness temperature (low frequency range in L–band around 1.4 GHz) which is directly linked to the dielectric constant–of the target area (i.e., moisture or salinity); hence, proportional to moisture or salinity. SSS retrieval requires knowledge of sea surface temperature and sea roughness and, additionally, it also requires a very high sensitivity from the sensor.

Sea Surface Temperature (SST). The SST at the very surface, within the top few micrometres, is termed SSST (“Skin” SST), and the SST immediately below is called the “bulk” SST. The skin SST may be significantly cooler, by as much as 1 K, than the bulk SST immediately

7005) D. G. Long, M. W. Spencer, “Radar Backscatter Measurement Accuracy for a Spaceborne Pencil–Beam Wind Scatterometer with Transmit Modulation,” *IEEE Transaction on Geoscience and Remote Sensing*, Vol. 35, No. 1, Jan. 1997, pp. 102–114

7006) G. Lagerloef, C. Swift, D. LeVine, “Sea Surface Salinity: The next remote sensing challenge,” *Oceanography*, 8, 1995, pp. 44–50

below it. This temperature difference is due to the fact that heat transfer is usually from the ocean to the atmosphere, and therefore the ocean is losing heat to the atmosphere by molecular conductance. Beneath the skin layer, the temperature may be relatively constant to a depth of a few metres if the ocean is well mixed, or there may be a pronounced temperature gradient known as the diurnal thermocline.

There are several factors that determine the skin–bulk temperature difference and the magnitude of the thermocline, but the principal ones are wind speed and the amount of incoming solar radiation. Both effects usually exhibit a diurnal cycle. The most favoured conditions for both the establishment of a skin–bulk difference and a thermocline are calm winds in strong sunlight.

Satellite instruments can only measure the skin SST, although the retrieval algorithms are formulated to attempt to give a “pseudo–bulk” SST.

Semiconductor junctions. Semiconductors whose principal charge carriers are electrons are called n–type (negative). If the charge carriers are mainly holes (a vacancy with positive charge), the material is p–type (positive).

Sensor. An instrument (generic term), usually consisting of optics, detectors, and electronics that collects radiation and converts it to some other form. The form may be a certain pattern (an image, a profile, etc.), a warning, a control signal, or some other signal. – The photographic camera is one of the best known examples of a ‘remote sensor’ which has been around since the first half of the nineteenth century.

Sensor characteristics. The ability of a sensor to detect and to resolve incoming radiation. For imaging sensors a very prominent characteristic is ‘ground resolution,’ its ability to distinguish objects on the Earth’s surface. Other sensor characteristics are: scene size, spectral range, spectral resolution, radiometric resolution, pointing accuracy (location knowledge), and timeliness (in which images are returned to the user, the frequency at which a given target can be revisited, the fraction of time that the sensor requires for taking an image).

Shielding. Refers to a technique of enclosing an object or a device within a container specifically designed to attenuate or otherwise exclude electromagnetic radiation.

SI (International System of Units — from the French *Système International d’Unités*). The present SI was officially established in 1960, its origin goes back to the creation of the metric system during the French Revolution. Following an idea proposed a century earlier by John Wilkins, the new system of weights and measures took as its starting point a single universal measure—the meter—and used it to define length, volume, and mass. The meter came from a perceived constant of nature: one ten–millionth of the distance along Earth’s meridian through Paris from the North Pole to the equator. ⁷⁰⁰⁷⁾

Definitions for the units of volume and mass followed, with the liter being 0.001 m^3 and the kilogram the mass of 1 liter of distilled water at 4°C . Subsequently, in 1799, two platinum artifact standards for length and mass based on those definitions were deposited in the Archives de la République in Paris. In the words of the Marquis de Condorcet, a new system of measurement “for all time, for all people” was born.

Seventy–six years later, the signing of the Meter Convention in 1875 established three international organizations: the General Conference on Weights and Measures (CGPM), the International Committee for Weights and Measures (CIPM), and the International Bureau of Weights and Measures (BIPM). They were formally tasked with maintaining the SI and continue to do so.

The SI is a living, evolving system, changing as new knowledge and measurement needs arise, albeit sometimes slowly when measured against the rapid pace of scientific progress.

⁷⁰⁰⁷⁾ David B. Newell, “A more fundamental International System of Units,” *Physics Today*, Vol. 67, Issue 7, 35 (2014); doi: 10.1063/PT.3.2448, URL: <http://dx.doi.org/10.1063/PT.3.2448>

For example, in the 18th and 19th centuries when natural philosophers and scientists tried to apply the system of length, mass, and time—with time defined by astronomical observations—to quantify newly discovered phenomena such as magnetism and electricity and the concept of energy, they also discovered the need for new units of measure. The likes of Carl Friedrich Gauss, Wilhelm Weber, James Clerk Maxwell, and Lord Kelvin, pioneers in the new science, helped to expand the system and developed the conceptual framework of a coherent system with base mechanical units from which to create derived units as needed. The system included clear explanations of how to realize the base units through measurement, and the coherent derived units were products of powers of the base units with a prefix of 1.

Sidelobes. See **antenna sidelobes**.

Sigma (σ). The conventional measure of the strength of a radar signal reflected from a geometric object (the target area). Sigma designates the strength of reflection in terms of the geometric cross section of a conducting sphere that would give rise to the same level of reflectivity. See also **radar cross section**.

Sigma naught (σ^0). Scattering coefficient, the conventional measure of the strength of radar signals reflected by a distributed scatterer, usually expressed in dB. It is a normalized dimensionless number, comparing the strength observed to that expected from an area of one m^2 . Sigma naught is defined with respect to the nominally horizontal plane, and in general has a significant variation with incidence angle, wavelength, polarization, as well as with the properties of the scattering surface itself.

Signal–To–Noise Ratio (SNR). The ratio of the level of information–bearing signal power to the level of noise power. The maximum SNR of a device is called the ‘dynamic range.’ In general, the higher the value of an instrument’s SNR, the better the signal quality for recognition (detection) and interpretation.

Signature. The response of electromagnetic radiation to particular objects in the target area. Signatures may be used for pattern recognition which may in turn lead to target identification.

- The radar signature is the radar response (differential radar cross–section or the scattering cross section) of a particular material or object as a function of frequency, angle, polarization, or time.
- The **spectral signature** is the radiation response of an object as a function of wavelength.

Silicon Carbide (SiC). Silicon carbide occurs in many different crystal structures (called polytypes) with each crystal structure having its own unique electrical and optical properties. In the 1990s and at the turn of the 21st century, SiC is becoming an important material in semiconductor electronics technology. This is due to the excellent performance characteristics of the material in: structure, optical properties, electrical characteristics, and mechanical properties. For instance, SiC–based electronics and sensors can operate in hostile environments such as in high–temperature applications up to 600°C (conventional Si–based electronics are limited to 350°C). SiC has also the ability to function under high–power (high–voltage switching, microwave electronics in communications, etc.) and high–radiation conditions. Significant performance enhancements are expected to a far–ranging variety of applications and systems. However, improvements in crystal growth and device fabrication processes are needed before SiC–based devices and circuits can be scaled–up and incorporated into electronic systems. – In addition, the SiC material offers some features very important to space instruments, like: low mass, high specific strength, and high optical quality for reflector surfaces. SiC–type ceramic mirrors and structures are becoming state–of–the–art technology components in lightweight optomechanical systems (telescopes).

Soil moisture. Soil moisture is an important variable controlling biogeochemical cycles, heat exchange and infiltration rates at the land/atmosphere boundary. Soil moisture content partitions rainfall into infiltration and runoff, and determines radiative sensible and latent heat.⁷⁰⁰⁸⁾ The microwave portion of the electromagnetic spectrum causes a large contrast between water and dry soil, offering the greatest potential for monitoring soil moisture.

Solar absorption technique. A method for measuring atmospheric constituents. As sunlight passes through the Earth's atmosphere, certain wavelengths are selectively absorbed by gaseous constituents. In the infrared region, nearly all gases have characteristic, discrete absorptions, whose positions and relative strengths are known from laboratory measurements of pure gas samples. This permits gaseous atmospheric constituents between the sun and an observer to be identified and quantified from high resolution solar spectra.

Solar cell. A solar cell or photovoltaic (PV) cell is an optoelectronic device (invented in 1954) that converts the radiant energy of sunlight directly into electrical power, based on photovoltaic principles. The solar cell is a large-area photodiode that detects the solar emission spectrum rather than a specific wavelength, as do photodiodes. The solar cell is unbiased, the load is connected directly across the two terminals of the p–n junction. Conversion efficiency, radiation hardness, and EOL (End Of Life) power are very important properties of solar cells. They are usually arranged in arrays or panels for spacecraft powering. During the 40 years of space technology, three generations of solar cells have been introduced:

- Silicon (Si) solar cells dominated the field until the early 1990s
- Gallium arsenide (GaAs) solar cells arrived in about 1990. They have better conversion efficiencies and radiation resistance in comparison with Si cells. GaAs cells can be manufactured on lightweight germanium substrates.
- The third generation of solar cells is the multifunction cell, or cascade cell. Current multijunction cells are based on GaInP (Gallium Indium Phosphide) material and GaAs on Ge substrate.

Note: **EOL efficiency.** This is the efficiency of the solar cell after many years of high energy particle irradiation in orbit. The EOL efficiency has to meet the power requirements of the satellite. The degradation of the cell characteristics under the high energy electron and proton irradiation depends on the semiconductor material and the specific solar cell structure.

Solar cycle. The solar cycle is the periodic change in the sun's activity (including changes in the levels of solar radiation and ejection of solar material) and appearance (visible in changes in the number of sunspots, flares, and other visible manifestations). Solar cycles have a duration of about 11 years. They have been observed (by changes in the sun's appearance and by changes seen on Earth, such as auroras) for hundreds of years. Solar cycles are numbered starting with the solar cycle of 1755–1766 (Solar Cycle 1). Solar cycle 24, the current solar cycle, started on January 8, 2008. NASA predicts that the solar cycle 24 will peak in early or mid 2013 with about 59 sunspots.⁷⁰⁰⁹⁾

The 11 year period between maxima (or minima) of solar activity is usually measured by the number of sunspots on the solar surface. About every 11 years the magnetic field of the sun **reverses polarity**; hence, the more basic period may be 22 years. It is generally accepted that the solar cycle is maintained by a dynamo driven by the differential rotation of the sun's envelope. – Empirical evidence from extensive climate data sets suggests the presence of an 11 year solar signal of the order 0.1 K in Earth surface, atmospheric and ocean temperatures.

7008) J. Li, S. Islam, "On the estimation of soil moisture profile and surface fluxes partitioning from sequential assimilation of surface layer soil moisture," *Journal of Hydrology*, Vol. 220, pp. 86–103, 1999.

7009) "Solar cycle," URL: http://en.wikipedia.org/wiki/Solar_cycle

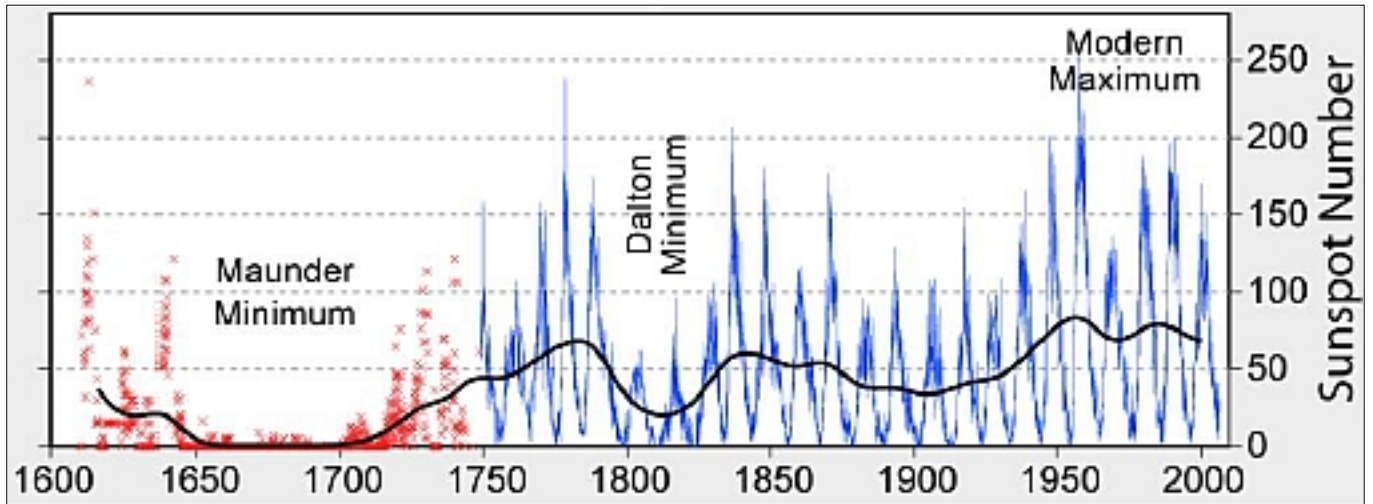


Figure 1605: 400 years of sun spot observations (image credit: NASA, Ref. 7011)

When the sun is at the maximum of its activity cycle, it is about 0.1% brighter overall, with an order of magnitude greater increase at UV wavelengths. In the early 21st century, it is established that climate forcing is well correlated with total solar irradiance and UV irradiance measurements obtained from high-precision spaceborne solar measurements spanning more than two decades of observations.

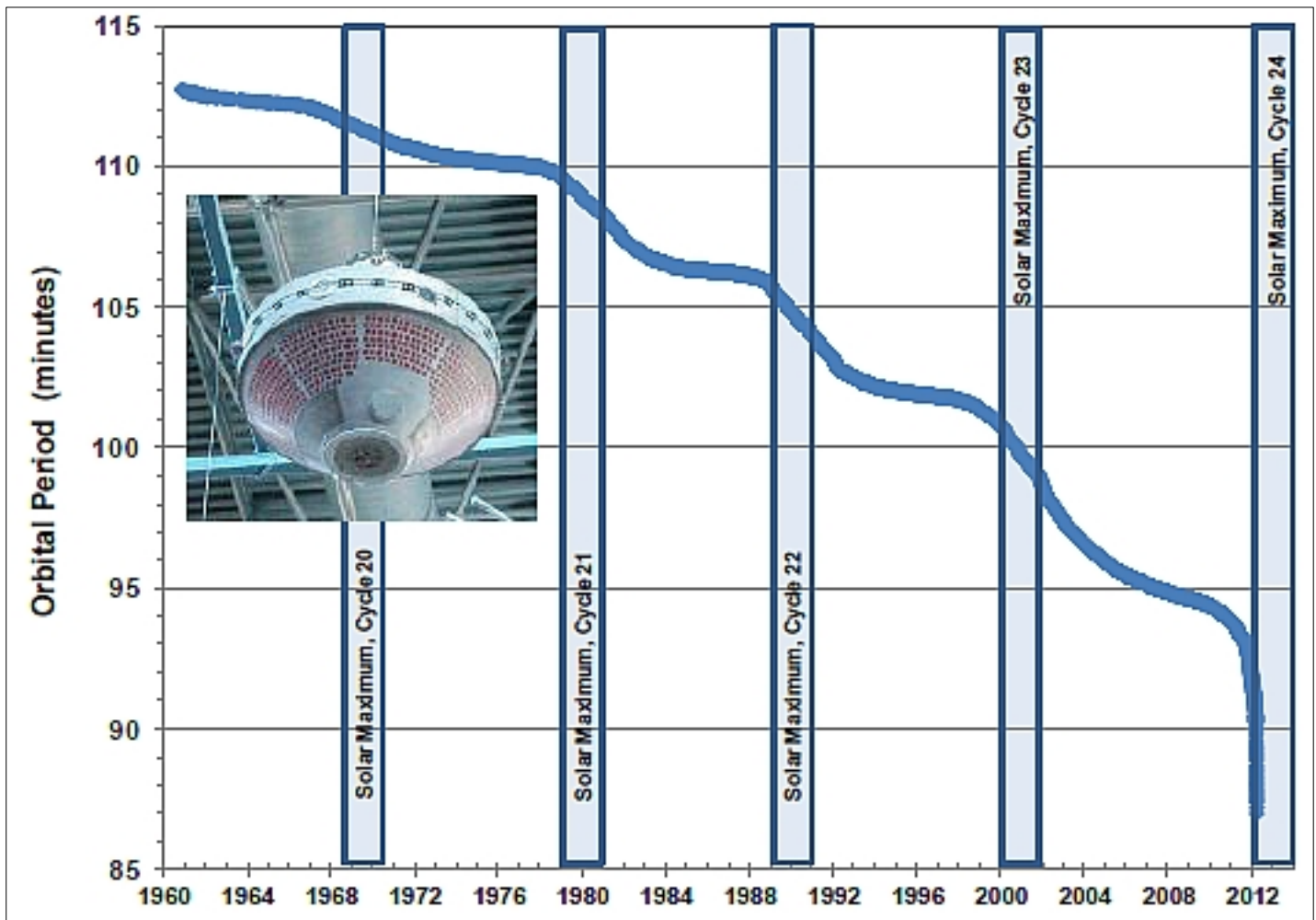


Figure 1606: The orbital decay of the Explorer 8 satellite was directly influenced by periodic increases in solar activity (image credit: NASA)

The best known consequence of high solar activity is an increase in the density of the thermosphere, which, in turn, increases drag on the vast majority of objects in LEO (Low Earth Orbit). The most prominent evidence of this is seen in a dramatic increase in space object reentries.

On 3 November 1960, the U.S. deployed the Explorer 8 spacecraft into an elliptical orbit of 420 km x 2290 km with an inclination of 50°. Although the spacecraft completed its mission after only two months, Explorer 8, with its relatively low perigee and high apogee, was in an ideal orbit to monitor changes in the density of the thermosphere under varying levels of solar activity. Figure 1606 illustrates the effect of the periodic solar maxima from the launch of Explorer 8 to its reentry in March 2012. Clearly, the rate of orbital decay increased in synchronization with high levels of solar activity. ⁷⁰¹⁰⁾

Solar cycle 24 (current cycle): Scientists agree that solar cycle 24 is unusual. The question is whether it is unusually unusual. The solar cycle is highly variable from maximum to maximum and also from minimum to minimum. We appear to be coming out of a period that has been labelled the "Modern Maximum," where the peak sunspot number has been higher than prior cycles as seen in historical records. ^{7011) 7012)}

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- 7010) Nicholas L. Johnson, "The effects of solar maximum on the Earth's satellite population and space situational awareness," Proceedings of the 63rd IAC (International Astronautical Congress), Naples, Italy, Oct. 1–5, 2012, paper: IAC–12.A6.2.9, URL: http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120002784_2012002209.pdf
- 7011) Madhulika Guhathakurta, "Status Update on Solar Max," Proceedings of the 50th Session of Scientific & Technical Subcommittee of UNCOPUOS, Vienna, Austria, Feb. 11–22, 2013, URL: <http://www.oosa.unvienna.org/pdf/pres/stsc2013/tech-30E.pdf>
- 7012) David H. Hathaway, "Solar Cycle Prediction," NASA/MSPC, Jan. 03, 2013, URL: <http://solarscience.msfc.nasa.gov/predict.shtml>

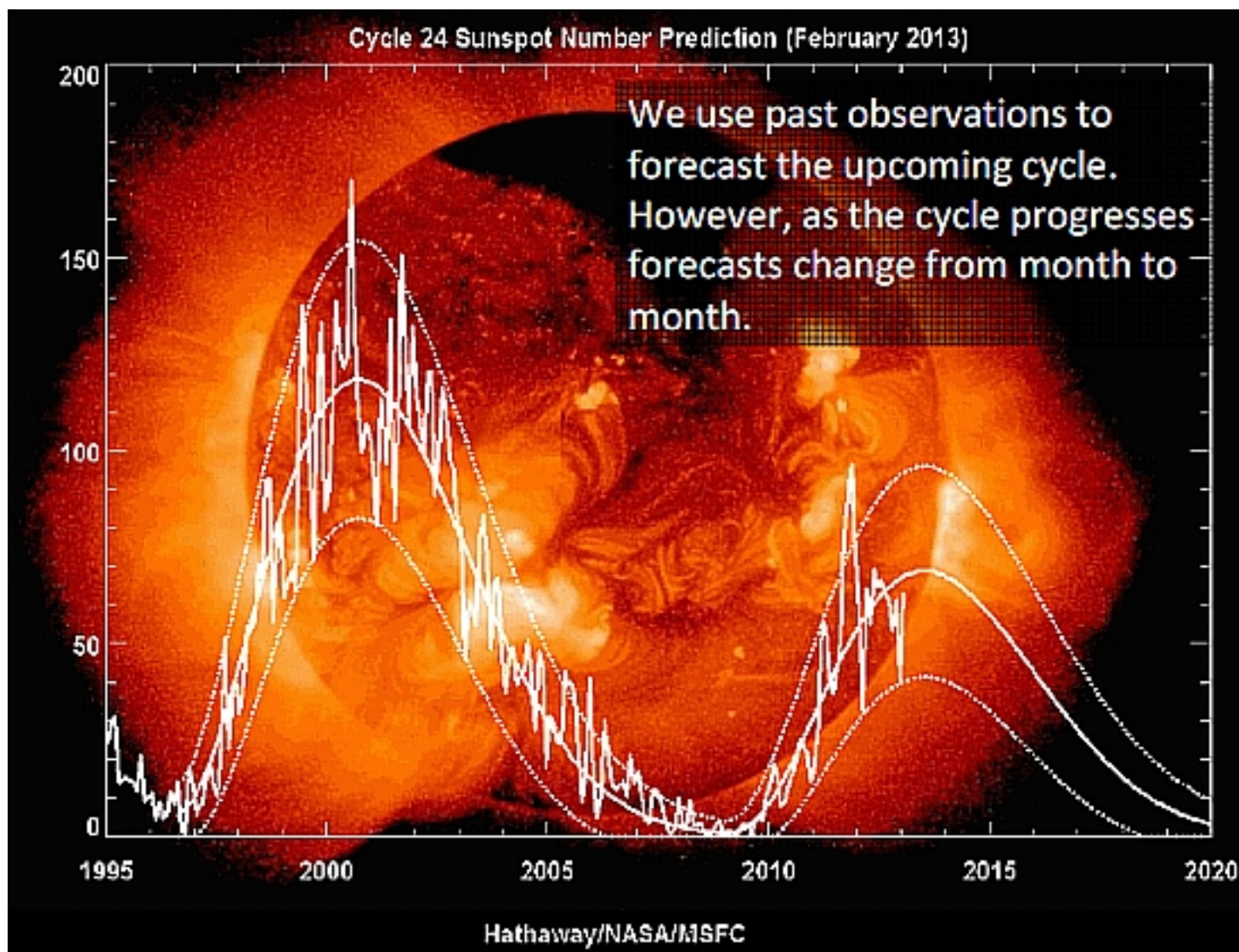


Figure 1607: The prediction for the next sunspot cycle maximum gives a sunspot number of about 64 in July 2013

The sunspot cycle and climate. The solar cycle affects climate in three key ways (Ref. 7011):

- Insolation from the Sun is slightly greater at solar maximum, warming the Earth.
- Galactic cosmic rays seed clouds, which affect Earth's albedo. They are inhibited at solar maximum, warming the Earth slightly.
- UV irradiance from the Sun changes Earth's outer atmosphere in ways that are still being determined.

Solar flares. A solar flare is a large explosion in the sun's atmosphere that can release as much as 6×10^{25} joules of energy (equivalent to millions of atomic bombs exploding simultaneously). During the occurrence of a solar flare, plasma is heated to tens of millions degrees Kelvin, while electrons, protons and heavier ions are accelerated to near the speed of light.

Solar flares affect all layers of the solar atmosphere (photosphere, corona, and chromosphere), heating plasma to tens of millions of kelvins and accelerating electrons, protons, and heavier ions to near the speed of light. They produce radiation across the electromagnetic spectrum at all wavelengths, from radio waves to gamma rays. Most flares occur in active regions around sunspots, where intense magnetic fields penetrate the photosphere to link the corona to the solar interior. Flares are powered by the sudden (timescales of min-

utes to hours) release of magnetic energy stored in the corona. If a solar flare is exceptionally powerful, it can cause CMEs (Coronal Mass Ejections).⁷⁰¹³⁾

X-rays and UV radiation emitted by solar flares can affect Earth's ionosphere and disrupt long-range radio communications of satellites. Direct radio emission at decimetric wavelengths may disturb operation of radars and other devices operating at these frequencies.

Solar flare activity can vary from several per day to only a few a month, depending mostly upon the overall activity of the sun as a whole. The prediction of solar flare occurrences has been problematic so far.

In 2009/2010, progress has been made in the prediction accuracy by Alysha Reinard and her team at NOAA's Space Weather Prediction Center in Boulder, CO. The long-sought clue to prediction lies in changes in twisting magnetic fields beneath the surface of the sun in the days leading up to a flare. The new technique permits advance predictions of solar flares up to 2–3 days. The NOAA team found that sound waves recorded from more than 1,000 sunspot regions reveal disruptions in the sun's interior magnetic loops that predict a solar flare. They found the same pattern in region after region: magnetic twisting that tightened to the breaking point, burst into a large flare, and vanished. They established that the pattern could be used as a reliable tool for predicting a solar flare.^{7014) 7015)}

Solar flux index F10.7: The solar radio flux at 10.7 cm wavelength (2800 MHz) is an excellent indicator of solar activity. Often simply called the **F10.7 index**, it is one of the longest running records of solar activity. The F10.7 radio emissions originates high in the chromosphere and low in the corona of the solar atmosphere. The F10.7 correlates well with the sunspot number as well as a number of UV (Ultraviolet) and visible solar irradiance records. The F10.7 has been measured consistently since 1947, first at Ottawa, and then at the Penticton Radio Observatory in British Columbia. Unlike many solar indices, the F10.7 radio flux can easily be measured reliably on a day-to-day basis from the Earth's surface, in all types of weather. Reported in "solar flux units", (s.f.u.), the F10.7 can vary from below 50 s.f.u., to above 300 s.f.u., over the course of a solar cycle.⁷⁰¹⁶⁾

The F10.7 Index has proven very valuable in specifying and forecasting space weather. Because it is a long record, it provides climatology of solar activity over six solar cycles. Because it comes from the chromosphere and corona of the sun, it tracks other important emissions that form in the same regions of the solar atmosphere. The EUV (Extreme Ultraviolet) emissions that impact the ionosphere and modify the upper atmosphere track well with the F10.7 index. Many UV emissions that affect the stratosphere and ozone also correlate with the F10.7 index. And because this measurement can be made reliably and accurately from the ground in all weather conditions, it is a very robust data set with few gaps or calibration issues.

Solar radiation – from Sun to Earth.⁷⁰¹⁷⁾ The enormous amounts of energy, continuously emitted by the sun, is dispersed into outer space in all directions. Only a tiny fraction of this energy is being intercepted by the Earth and other solar planets. The solar energy reaching the periphery of the Earth's atmosphere was considered to be constant for all practical purposes (it actually varies slightly), and is known as the solar constant. The accepted mean value is 1,353 W/m².

Outer space: In passing through outer space, which is characterized by vacuum, the different types of solar energy remain intact and are not modified until the radiation reaches the

7013) http://en.wikipedia.org/wiki/Solar_flare

7014) "NOAA Scientist Finds Clue to Predicting Solar Flares," January 19, 2010, URL: http://www.noaanews.noaa.gov/stories2010/20100119_solarflare.html

7015) Alysha Reinard, Justin Henthorn, Rudi Komm, Frank Hill, "Evidence that temporal changes in solar subsurface helicity precede active region flaring," The Astrophysical Journal Letters, Vol. 709, No 2, Feb. 2010

7016) NOAA Space Weather Prediction Center, URL: <http://origin-www.swpc.noaa.gov/phenomena/f107-cm-radio-emissions>

7017) <http://almashriq.hiof.no/lebanon/600/610/614/solar-water/unesco/21-23.html>

top of the earth's atmosphere. In outer space, therefore, one would expect to encounter the following types of radiation: gamma ray, X-ray, ultraviolet, and infrared radiations.

Atmospheric effects: Not all of the solar radiation received at the periphery of the atmosphere reaches the surfaces of the Earth. This is because the Earth's atmosphere plays an important role in selectively controlling the passage towards the Earth's surface of the various components of solar radiation.

A considerable portion of solar radiation is reflected back into outer space upon striking the uppermost layers of the atmosphere, and also from the tops of clouds. In the course of penetration through the atmosphere, some of the incoming radiation is either absorbed or scattered in all directions by atmospheric gases, vapors, and dust particles. In fact, there are two processes known to be involved in atmospheric scattering of solar radiation. These are termed **selective scattering** and **non-selective scattering**. These two processes are determined by the different sizes of particles in the atmosphere.

Spectral band	Wave range (nm)	Atmospheric effects
Gamma rays	< 0.003 nm	Radiation is completely absorbed by upper atmosphere
X-rays	0.003 – 6	Radiation is completely absorbed by upper atmosphere
Ultraviolet UV (B) (EUV, FUV, some UV)	6 – 300	Radiation is completely absorbed by oxygen, nitrogen, and ozone in the upper atmosphere
Ultraviolet UV (A) (NUV)	300 – 400	Radiation transmitted through the atmosphere, but atmospheric scattering is severe
Visible light (VIS)	400 – 700	Radiation is transmitted with moderate scattering for shorter wavelengths
Infrared reflected (NIR, SWIR)	700 – 3000	Mostly reflection radiation
Thermal infrared (MWIR, TIR)	3000 – 14,000	Absorption at specific wavelengths by carbon dioxide, ozone, and water vapor, with major atmospheric windows

Table 976: Spectral regions of incoming solar radiation and atmospheric effects

- Selective atmospheric scattering is, broadly speaking, inversely proportional to the wavelength of radiation and, therefore, decreases in the following order of magnitude: EUV > near UV > violet > blue > green > yellow > orange > red > infrared. Accordingly, the most severely scattered radiation is that which falls in the ultraviolet, violet, and blue bands of the spectrum. The scattering effect on radiation in these three bands is roughly ten times as great as on the red rays of sunlight. – It is interesting to note that the selective scattering of violet and blue light by the atmosphere causes the blue color of the sky.

- Non-selective scattering occurring in the lower atmosphere is caused by dust, fog, and clouds with particle sizes more than ten times the wavelength of the components of solar radiation. Since the amount of scattering is equal for all wavelengths, clouds and fog appear white although their water particles are colorless. Atmospheric gases also absorb solar energy at certain wavelength intervals, called absorption bands, in contrast to the wavelength regions characterized by high transmittance of solar radiation, called atmospheric transmission bands, or atmospheric windows.

Ground level: As a result of the atmospheric phenomena involving reflection, scattering, and absorption of radiation, the quantity of solar energy that ultimately reaches the Earth's surface is much reduced in intensity as it traverses the atmosphere. The amount of reduction varies with the radiation wavelength, and depends on the length of the atmospheric path through which the solar radiation traverses. The intensity of the direct beams of sunlight thus depends on the altitude of the sun, and also varies with such factors as latitude, season, cloud coverage, and atmospheric pollutants.

The total solar radiation received at ground level includes both direct radiation and indirect (or diffuse) radiation. Diffuse radiation is the component of total radiation caused by atmo-

spheric scattering and reflection of the incident radiation on the ground. Reflection from the ground is primarily visible light with a maximum radiation peak at a wavelength of 555 nm (green light). The relatively small amount of energy radiated from the Earth at an average ambient temperature of 17° C at its surface consists of infrared radiation with a peak concentration at 970 nm. This invisible radiation is dominant at night.

Solar radiation pressure (SRP). Refers to a force on the surface of a body (normally a spacecraft) due to a) the impact of solar photons, b) the related effects of anisotropic thermal re-radiation of the body, and c) the albedo force. In the long term, these three interrelated tiny (non-conservative) forces can have a strong perturbing effect on the orbit of a satellite. With the increased accuracy requirements for many geodetic/altimeter satellites, it has become necessary to have more accurate methods for modeling these forces. While the net incident radiation reaching the satellite is well known, the characteristics of the satellite's surfaces (i.e. specular and diffuse reflectivity) and their time-dependent behavior requires some analysis.⁷⁰¹⁸⁾

Solar sail. A low-thrust propulsion technology (in the experimental/demonstration phase at the start of the 21st century) whose concept relies on the momentum transfer of photons (solar radiation pressure) on large, highly reflecting sails in space for passive propulsion such as orbit transfer functions. The concept involves the deployment and control (orientation) of a large sail in orbit on lightweight structures. The technology of such solarcraft is of interest for interplanetary missions.

At Earth distance from the sun, the solar flux, S_s is about 1.4 kWm^{-2} . If one assumes perfect reflectivity from the mirror (perfect reflection of sail), the force due to this flux is given as:

$F = ma = 2(S_s \times A)/c$ [where A is a unit area of sail surface (1 m^2) and c is the speed of light ($c = 3 \times 10^{10} \text{ m/s}$)]

$F = 9.3 \times 10^{-6} \text{ N}$ (the force or solar radiation pressure on 1 m^2 of sail surface normal to the sun). This force is indeed very small. Hence, large sail surface areas are needed to come up with a noticeable force for a lightweight spacecraft.

Solar wind. A radial outflow of plasma from the solar corona, carrying mass and angular momentum away from the sun (see chapter Q.17). The solar wind consists of a flux of particles, chiefly protons and electrons together with nuclei of heavier elements in smaller numbers, that are accelerated by the high temperatures of the solar corona, or outer region of the Sun, to velocities large enough to allow them to escape from the sun's gravitational field. At 1 au (astronomical unit) the solar wind contains approximately $1-10 \text{ protons/cm}^3$ moving outward from the sun at velocities of 350 to 700 km/s (or about 1.26 – 2.52 million km/h); this creates a positive ion flux of 108 to 109 ions/($\text{cm}^2 \text{ s}$), each ion having an energy equal to at least 15 eV (electron volts). During solar flares, the proton velocity, flux, plasma temperature, and associated turbulence increase substantially. The solar wind represents a mass loss from the sun of $\sim 10^{15} \text{ kg}$ per year.

Solid Earth dynamics: The 'solid Earth' processes are those affecting the surface and interior of the planet. This topic refers to the characteristics of crustal deformation in regions of active tectonic activity and the processes driving the solid Earth's dynamics. This study field includes atmosphere angular momentum variations, ocean tides and currents, and core flow dynamics and angular momentum transfer between the various interfaces of this complex system.

Tectonic processes driven by mantle convection and associated deformation at the surface, leading to earthquakes and volcanic activity, are affecting daily life for millions of people. The global distribution of gravity is indicative of such processes in the interior, a driver for ocean currents, and sensitive to mass redistribution, for example, due to melting land ice.

⁷⁰¹⁸⁾ M. Ziebart, P. Cross, S. Adhya, "Modeling Photon Pressure – The Key to High-Precision GPS Satellite Orbits," GPS World, Jan. 2002, pp. 43–50, part of the Innovation Column, coordinated by R. B. Langley

Anomalies in the magnetic field tell us more about Earth's geological history and mass motion in its fluid core.

Sounder. A remote sensing instrument that measures incoming radiation spectrum (trace gases, temperature, pressure, moisture, trace gases,) of the atmosphere in a particular plane of observation obtaining profiles along a path. The various profile heights of the measurements can be determined by the state parameters. A sounder may be a passive device by measuring the incoming radiation, it can also be an active device, transmitting signals (echo sounding) and receiving the echo information. Two basic configurations are in use:

- In the nadir-viewing configuration the observation plane is the orbit plane of the platform (series of footprints along the suborbital track). The scan technique provides good horizontal resolution of the measurements, but usually poor vertical resolutions.
- Limb sounders look at the horizon (the limb) and scan vertically, producing good vertical resolution but poor horizontal resolution.

Sounding. To 'sound' (to find bottom) originally referred to the measurement of water depths by sounding methods (sounding line, echo sounding, etc.) in shallow coastal waters and in rivers. The technique was much later extended to measure also the conditions of another medium, namely the atmosphere, at various heights. The first devices used were balloons with self-registering instruments (referred to as sondes) to record meteorological data. As new technologies became available, radiosondes, dropsondes from aircraft, rawinsondes, sounding rockets, ground-based, airborne and spaceborne instruments of a great variety appeared.

Spacecraft/platform attitude sensing and control devices.

A S/C attitude or pointing direction is determined by comparing information from various onboard sensors with the positions of known references. Attitude knowledge may be derived from the following orientation instruments:

- Magnetometers (measuring the known magnetic field components)
- Sun and/or star sensors or trackers (measuring of known celestial body directions)
- Earth horizon sensors (various types, mostly in the IR region; a horizon crossing indicator may determine the attitude of a spin-stabilized S/C with respect to the Earth; another horizon sensor may measure one component of the attitude of a three-axis stabilized S/C with respect to the Earth; there are scanning IR Earth horizon sensors, etc.).
- Gyroscopes (measuring inertial reference)
- GPS receiver (capable of measuring attitude). These GPS attitude instruments provide attitude and attitude rate data to actuators for real-time, autonomous attitude determination.
- Telescope (instrument guide telescope)
- etc.

The following instruments (or combinations thereof), referred to as actuators, provide attitude control:

- Momentum gyros
- Reaction/momentum wheels
- Thrusters (cold gas thrusters, solid thrusters, ion thrusters, mono- or bi-propellant engine, etc.)
- Magnetic torque coil/rods (magnetorquers)

- Permanent magnets
- Gravity gradient boom
- Nutation damper
- etc.

The simplest attitude control system is passive stabilization, either magnetically (a magnetometer as sensor in combination with a magnetic torque rod as actuator) or by gravity gradient methods. Passive stabilization can also be combined with active components, e.g. gravity gradient systems with magnetic torquers are quite common.⁷⁰¹⁹⁾ Simple spinners, and momentum biased satellites represent the next advanced level of attitude control system, requiring at least for the momentum biased system some active stabilization about the angular momentum axis (typically the pitch axis). Zero-momentum systems with either reaction wheels or thrusters are the most complex systems, they require constant stabilization and become unstable if control is lost only for a short period of time. Simple and passively stable systems have a low pointing performance, and complex systems using reaction wheels are highly accurate pointing systems.

Spacecraft/platform disturbance torques. The following list is a summary of typical disturbance torques on a platform:

- Aerodynamic drag force (in LEO applications). A torque is created between the CM (Center of Mass) and the CP (Center of Pressure) of the drag force. Atmospheric drag due to the low perigee creates an acceleration on the spacecraft which tends to decrease its orbital energy, and thus, the orbit “decays”
- Earth’s geopotential, namely the **J₂ term** of the Earth’s oblateness. The perturbation due to the Earth’s J₂ term has the tendency to precess both the Line of Apesides (the line connecting perigee and apogee) and the Line of Nodes (the line connecting the ascending and descending nodes).
- Gravity gradient: A gravitational field variation is created by long and extended spacecraft structures (this applies in particular to booms, tethers, etc.)
- Internal torques: May be generated by onboard equipment (wheels, cryocoolers, pumps, etc.)
- Magnetic torques are induced by the residual magnetic moment
- Mass expulsion: these are torques created by thrusters (including electric propulsion)
- Solar radiation: A torque is induced by the CM and CP offset.

Spacecraft/platform and instrument pointing. Good location knowledge of a target (of the ground surface, of a celestial body, etc.) by instrument pointing is an ever-present requirement of many missions (in particular for astronomy instrument pointing, also when imagery of the Earth’s surface is used for cartographic applications). Precision pointing capability is the result of spacecraft stability through suitable attitude sensing and control mechanisms (some systems may include vibration control, elimination of alignment errors due to thermal distortions, etc.). In general structural stiffness of the platform is an important prerequisite for a stable pointing environment. There are several classes of instruments with regard to pointing capability:

- Rigid-body instrument pointing or simply **body pointing**. This refers to a no-instrument-pointing capability relative to the platform. Most observation instruments on a spacecraft platform are fixed, they point into a constant direction (nadir, off-nadir, limb,

⁷⁰¹⁹⁾ H. J. Koenigsmann, G. Gurevich, “AttSim, Attitude Simulation with Control Software in the Loop,” Proceedings of the AIAA/USU Conference on Small Satellites, Aug. 23–26, 1999, Logan UT, SSC-IIa-5

zenith, etc.), their FOV (Field of View) provides a sufficient scan capability (for instance in the cross-track direction, and/or in the height direction) to measure all resolution cells in a swath.

- Some S/C with body-pointed (fixed) instruments are able to employ maneuvers to turn the entire S/C into a desired direction (example: IKONOS-1) thereby extending the field of regard considerably for observations outside of the normal swath width. S/C with relatively small masses (microsatellites) are most suited for this choice of pointing implementation.
- Instrument pointing relative to the platform. This class of sensors performs inertial pointing/tracking of a star or simply pointing/tracking of the sun or the moon. Some observation instruments need to be kept pointed for relatively long periods of time with extraordinary precision at faint celestial bodies. However, most instruments in this class are attitude sensors (such as: gyroscopes, magnetometers, horizon sensors, star or sun sensors, star trackers, accelerometers), their measurements serve as input for the onboard attitude control subsystem. The pointing knowledge bounds of a platform are always smaller than the actual pointing control bounds.
- Instrument pointing capability relative to the platform. These are observation instruments (imager, etc) performing fairly quick slew maneuvers, for instance in the along-track direction, to obtain stereo imaging.

SAR's capability to form good imagery relies significantly on the stability of the platform and, if the stability is not satisfactory, the precise knowledge of attitude information can be used to correct for orbital effects. On-board accurate and precise attitude/position determination is required, and in case of interferometry, most demanding. The baseline knowledge required is in the order of millimeter and the attitude of the baseline in the order of several arcseconds.

In an effort to achieve very precise aiming, ESA built a Spacelab system by the name of IPS (Instrument Pointing System – first flown on STS-51-F as Spacelab-2 in July/Aug. 1985). This three-axis gimbal pointing system provides precision pointing and tracking capabilities by establishing an inertially stable base from which stellar, solar, and Earth observations can be made (maintenance of pointing stability is within ± 1.2 arcseconds).⁷⁰²⁰⁷⁰²¹ – In the same context, MACE (Middeck Active Control Experiment) is a NASA precision pointing system (built by MIT, LaRC, LMSC, et al.) flown on Shuttle flight STS-67 in March 1995, with the objective to explore high precision pointing and vibration control of future spacecraft and satellites. MACE extends conventional rigid-body instrument pointing to include flexible modes. Tests were conducted on the free-floating MACE platform to measure how disturbances caused by a payload impacts the performance of another nearby payload which is attached to the same supporting structure. MACE accomplishments: a) About 50 LaRC control systems were experimentally evaluated on-orbit, b) a reduction of at least 19 dB was achieved in the vibration levels, and c) MACE was able to synthesize and evaluate new control designs during the STS-67 flight.

Spacecraft/platform stabilization. Techniques that control the orientation (attitude) of the spacecraft in orbit with respect to certain known references. Several of the methods in use are:

- Single-spin stabilization. The whole spacecraft body rotates about the axis of the principal moment of inertia (acting like a gyroscope). These satellites cannot have oriented antennas, a severe drawback for certain applications.

⁷⁰²⁰) K. K. Denoyer, R. S. Erwin, R. R. Ninneman, "Advanced SMART Structures Flight Experiments for Precision Spacecraft," *Acta Astronautica*, Vol. 47, No 2-9, 2000, pp. 389-397

⁷⁰²¹) J. A. Woods-Vedeler, L. G. Horta, "On-Orbit Application of H-Infinity to the Middeck Active Controls Experiment: Overview of Results," *AAS*, 1996-189

- **Dual–spin stabilization.** A configuration in which the spacecraft consists of two parts: the platform, which is oriented toward the Earth, and the rotor, which rotates about the principal axis of the S/C thereby providing gyroscopic stiffness (example: Meteosat).
- **Three–axis stabilization.** A configuration in which the entire spacecraft is oriented toward a particular direction (usually toward the Earth in one dimension and aligned to the flight path in the other dimension). The control torques for attitude control are provided by a combination of reaction/momentum wheels, magnetotorquers, torque rods, gimbal system, and/or thrusters. In this concept, the rotating **reaction wheels** are able to absorb torque and momentum, while magnetic torquers or thrusters are used of allowing the wheels to slow their rotation rate. The same attitude control function may also be provided by an all–thruster system.
- **Gravity gradient stabilization (passive stabilization method).** A spacecraft consisting of two masses (main mass and small mass) that are connected by a rod or a boom. This two–mass arrangement produces a gravity gradient along the boom axis and an associated small torque which is employed for spacecraft orientation. This technique is normally used along with magnetic torquing (yet another passive stabilization method) for better attitude control of small satellites (mini, micro, or nanosatellites).

Platform or Instrument	Pointing Knowledge	Pointing Accuracy (Control)
TIROS–N		0.1°
Spot–1 to –3		0.1°
ENVISAT	<0.03°	< 0.1° (3 sigma)
GP–B (relativity mission)		< 20 milliarcseconds (rms)
UoSAT		2–3° (rms) gravity–gradient boom system
DMSP (Block 5D–3)		0.01° (three orthogonal gyros)
SOHO		1 arcsecond (sun pointing over a period of 1.5 min)
TRACE		20 arcseconds (correction for pointing jitter)
Landsat–7	45 arcseconds	180 arcseconds
MSX		<0.1° (post–processing knowledge of 9 µrad)
GFO–1		0.25° (3 sigma)
Microlab–1		±2° gravity gradient boom system
IPS (Shuttle)		±1.2 arcseconds
CERES (on EOS)	180 arcseconds	
MISR (on EOS)	90 arcseconds	
SeaWinds	500 arcseconds	
OSA (on CRSS, also referred to as Ikonos–1)	Rms ground location accuracy: 2 m relative (with ground control points) 12 m absolute (without the use of control points)	

Table 977: Typical pointing parameters of a few satellites/instruments

Spacecraft/platform types (bus definitions):

In the 21 century, many terms are being used in the space industry to describe satellite bus architectures (standard bus, modular bus, plug–and–play bus, etc.). Definitions are provided according to the following reference: ⁷⁰²²⁾

- **Standard Bus:** A bus with a standard launch vehicle and payload interface that can be purchased unaltered. The expectation is that the bus can be purchased by the government

⁷⁰²²⁾ Peter M. Wegner, Phil Blower, Jason Wilkenfeld, “Standard Buses, Modular Buses, and Plug–and–Play Buses; what is the difference and why does it matter?,” Proceedings of the IAA Symposium on Small Satellite Systems and Services (4S), Rhodes, Greece, May 26–30, 2008, ESA SP–660, August 2008

and delivered to a systems integrator for integration with the payload and subsequent testing.

- **Customizable Bus:** A bus from a standard product line that is modified to meet specific mission needs. This category includes most of what industry today calls a standard bus.
- **Modular Bus:** A bus that is assembled from modular components with standard interfaces and minimal interdependencies between modules. In the early developmental states, extensive system integration and testing is required.
- **Plug-and-Play Bus:** A modular bus with open standards and interfaces, self-describing components, and an auto-configuring system. System integration is simple and testing tasks are automated. There are two key differences between a Plug-and-Play satellite bus and spacecraft that have been previously developed. That is: 1.) the use of auto-configuring hardware and software interfaces between the modules, and 2.) these interface standards are described by Open-System Standards.

Space surveillance: Refers to the detection, tracking, propagation, cataloguing and analysis of active and inactive Earth orbiting objects. Satellite orbits evolve in very complex ways requiring persistent surveillance by making repeat observations on them using ground-based sensors. Currently (2007), the number of tracked objects in Earth orbit numbers over 9000 with only a few hundred of these being active, operating spacecraft and payloads. The remainder of tracked objects are uncontrolled rocket bodies and debris posing collision threats to manned and high-value unmanned spacecraft. Space surveillance provides current and predictive information on these objects.

Space-Time Adaptive Processing (STAP).⁷⁰²³ STAP refers to a class of 2-D or 3-D signal processing techniques (space-time, space-frequency, direction-frequency) for sensor arrays. The spatial dimension is given by the geometry of the sensor array, the temporal dimension by the sequence of received echo pulses (slow time), or by range samples (fast time). A prerequisite for STAP operations is a coherent radar with a digitized multi-channel array antenna. The main application of STAP techniques is the detection of low Doppler targets buried in a strong clutter background by a moving (airborne, spaceborne) radar system. STAP can compensate the induced Doppler spreading effect of the moving platform so that targets with low radial velocity can be detected.

Space weather. This term refers to the conditions in space that affect the Earth and its space environment. Space weather is a consequence of sun behavior, the nature of Earth's magnetic field and atmosphere (in particular the ionosphere and magnetosphere), and Earth's location in the solar system. The solar wind, propagating against the Earth's magnetic field and interacting with it, shapes the near-Earth space environment. The response of the Earth's space environment to the solar wind is termed '**space weather.**' Space weather can influence the performance and reliability of spaceborne/airborne electronic systems as well as of groundbased systems (power and communication systems) and can endanger human life and health (spacewalks of astronauts). Other effects are: aurora and changes of climate.

Spatial frequency. Representation of an object or an image as a superposition of sinusoids (Fourier components).

Specific impulse. The specific impulse (Isp) of a thruster is the impulse (a force applied for a certain time) exerted with 1 kg of propellant. Therefore the units for specific impulse are Newton-seconds per kilogram (Ns/kg). By inserting the units of a Newton ($1\text{N} = 1\text{kgm/s}^2$), the numerical value of the specific impulse also corresponds to the effective exhaust velocity (m/s) of the gas exiting the thruster in a vacuum (see also Q.12.1.1).

Speckle. Refers to the phenomenon of a strong variation of echo signals from one resolution cell to another occurring in radar imaging (it is sort of a granular noise that affects the SAR

⁷⁰²³) http://www.fhr.fgan.de/fhr/el/el_rsrch_stap00_e.html

images). Speckle occurs because the echo received consists of the sum of contributions of point targets in a each resolution cell, in continuously changing combinations (see also chapter Q.8.5). Speckle is caused by the random interference of wavelets scattered by the microscopic fluctuations of the object surface within a resolution cell. The presence of speckle in an image decreases the radiometric resolution, and thus reduces interpretability of the image (reduction in detail). Usually, filters are used to reduce the effects of speckle.

Spectra (of dispersion). Common methods are: (see also Table 1236)

- Refraction: prisms are used to break up or disperse electromagnetic radiation into its component colors. The path of the radiation bends (refracts) when it passes from one medium into another.
- Diffraction: a lightwave breaks up into waves travelling in all directions as it strikes a surface. Diffraction gratings are composed of closely spaced transmitting slits on a flat surface (transmission gratings), or alternately reflecting and nonreflecting grooves on a surface (reflecting gratings).
- Interference: see **Interferometer**.
- Filter (electronically tunable filters)
- Filter (mechanical)
- Filter (mask)

Spectral and spatial purity. An evaluation of the quality of radiometric measurements in the spectral and spatial domains.

Spectral band. An interval in the electromagnetic spectrum defined by two wavelengths, two frequencies, or two wavenumbers.

Spectral region. See chapter 1.33 in the “history” part of the documentation.

Spectral resolving power. Ratio of $\lambda/\Delta\lambda$ (see also an example under **Wavenumber**).

Spectral signature. Quantitative measurement of the spectral properties of an object at one or several wavelength intervals.

Spectrometer. An instrument connected to a telescope that separates the light signals into different wavelengths or frequencies, producing a spectrum (thus permitting an analysis of the spectral content of the incident electromagnetic radiation). Usually, only a relatively small portion of the spectrum is measured by an instrument. Some spectrometer types are:

1) **Dispersive systems:** A class of spectrometers using the dispersive principle to separate radiation into its narrow-band components (spectral discrimination). A dispersive imaging spectrometer can only support one dimension of imaging (along the slit); the other dimension is used for spectral dispersion. Images are built up by making successive exposures; hence, images are stacked side by side. This is done either by using the motion of an aircraft or spacecraft (pushbroom imaging) or by the use of a sideways-scanning mirror (whiskbroom imaging).

– Prism spectrometer. From a historical point of view, glass prisms were first used to break up or disperse light into its component colors. The path of a light beam bends (refracts) as it passes from one transparent medium to another, e.g., from air to glass. A prism is used, along with collimating and re-imaging optical and mechanical components, to disperse light for spectral discrimination.

– Grating (diffraction) spectrometer. A grating is used (along with collimating and re-imaging optical and mechanical components) to disperse light by diffraction for spectral

discrimination. The spectral dispersion is stated, for example 2–4 nm/mm at 300 nm, and the resolution is 0.5 nm.

- In a wedge spectrometer spectral discrimination occurs in a focused beam
- 2) **Filter Spectrometers (nondispersive systems).** Filters are used to control the spectral bandwidth of the radiation that is allowed to reach the detector system. Narrowband filters are in the order of $1\text{--}2\text{ cm}^{-1}$.
 - Filter–wheel technique. Allows the selection of up to n discrete spectral bands.
 - Bandpass filter technique. Allows the transmission of only a narrow band of frequencies (the other frequencies are blocked out). The spectral width of this filter is characterized by its bandwidth. A typical bandpass filter instrument is TM on Landsat
 - Filter mask technique in which the spectral separation filters are mated to the detector array to achieve two–dimensional sampling of the combined spatial/spectral information passed by the filter. A typical instrument of this type is WIS (Wedge Imaging Spectrometer)
 - Dichroic systems. A filter method allowing selective absorption in crystals of electromagnetic radiation vibrating in different planes (usually filtering is based on wavelength). The dichroic principle is applied to beam splitters and filters.
 - Interference filter. A filter reflecting radiation selectively in a narrow spectral band
 - 3) **Fourier Transform Spectrometers (FTS, nondispersive systems).** An FTS system provides a conventional spectrum, but with greater speed, resolution and sensitivity. This class of spectrometers separates the incoming broadband spectrum into narrow–band components with the use of an interferometer. An incoming wavefront into the interferometer is divided by a beam splitter (semitransparent surfaces). Beams produced in this way travel two different paths, then recombine (superposition principle), creating an interferogram. This interferogram (a function of signal intensity versus time) is normally digitized and converted to an absorption spectrum by means of a Fourier transform. Instruments with high resolving power often use interferometers in series with grating instruments. FTS can be designed to cover all spectral regions from the radio frequency to the UV.
 - 4) **Correlation Spectrometers**, also referred to as NDIR (Non–Dispersive Infrared) spectrometers. A correlation spectrometer, or an autocorrelation spectrometer (**ACS**) is a device for a gas–specific investigation that correlates the spectral signatures of the species to be analyzed with reference spectra. In a digital autocorrelation spectrometer core, the signal is first translated and conditioned in a few analog processing steps before the digitizing and correlation.
 - 5) **AOS (Acousto–Optical Spectrometer).** The principle of an AOS is based on the diffraction of light at ultrasonic waves. A piezoelectric transducer, driven by the RF–signal (from the receiver), generates an acoustic wave in a crystal (the so called Bragg–cell). This acoustic wave modulates the refractive index and induces a phase grating. The Bragg–cell is illuminated by a collimated laser beam. The angular dispersion of the diffracted light represents a true image of the RF–spectrum according to the amplitude and wavelengths of the acoustic waves in the crystal. The spectrum is detected by using a single linear diode array (CCD), which is placed in the focal plane of an imaging optics.
 - 6) **Heterodyne Spectrometers** (nondispersive systems). See **Heterodyning**.
 - 7) Lidar Spectrometers.

Spectrometry. In remote sensing, spectrometry refers to the detection and measurement of radiation spectra of a target (area or volume). Each spectra has a characteristic pattern of absorption and emission bands. Comparison of these spectra against reference spectra pro-

vide information on the target's material composition. Imaging spectrometry refers to the simultaneous acquisition of images in many contiguous spectral bands.

System Technology	Spectral Resolving Power $\lambda/\Delta\lambda$	Wavelength Range	Moving Parts	Simultaneous Acquisition of all spectral bands	Throughput
Grating (CCD detectors)	$10^2 - 10^5$	Narrow (optics-limited)	no	yes	low
Prism	$10^2 - 10^3$	Narrow (optics-limited)	no	yes	low
Fourier Transform Spectrometer (FTS)	10^6	Broad (detector-limited)	yes (no, depending on type)	yes	very high
Filter (electronically tunable)	10^2	Narrow (optics-limited)	no	no	very high
Filter (mechanical)	10^3	Broad (detector-limited)	yes	no	very high
Filter (mask)	10^2	Narrow (optics-limited)	no	yes	very high
Filter (mask) WIS	10^2	Broad (detector-limited)	no	no	very high

Table 978: Overview of some spectrometer technology characteristics

Spectroradiometer. A combination of spectrometer and radiometer for measuring the energy distribution of emitted radiation.

Spectroscopy – differential absorption spectroscopy. A technique that uses two frequencies emitted by the same laser or by different lasers to perform measurements of the concentration of a gas along a given line of sight. The frequency of one laser signal is tuned to the frequency of the center line of the absorption feature; the frequency of the other laser signal is tuned aside from this feature. The difference in the amount of transmitted light at these two frequencies is the quantity that is being sought.

Spectroscopy – imaging.⁷⁰²⁴⁾ Imaging spectroscopy is the simultaneous acquisition of spatially coregistered images, in many, spectrally contiguous bands, measured in calibrated radiance units, from a remotely operated platform. Note: In the literature, the terms imaging spectroscopy, imaging spectrometry and hyperspectral imaging are often used interchangeably.

Background: Three centuries ago Sir Isaac Newton published in his “Treatise of Light” the concept of dispersion of light. The corpuscular theory by Newton was gradually succeeded over time by the wave theory, resulting in Maxwell’s equations of electromagnetic waves. But it was only in the early 19th century that quantitative measurement of dispersed light was recognized and standardized by Joseph von Fraunhofer’s discovery of the dark lines in the solar spectrum (1817) and their interpretation as absorption lines on the basis of experiments by Bunsen and Kirchhoff. Further pioneers in this field were Angstrom and Thalén.

The term “spectroscopy” was first used in the late 19th century and provides the empirical foundations for atomic and molecular physics. In the 1860s, the phenomenon of emission lines from the Sun’s corona was discovered. Following this, astronomers began to use spectroscopy for determining radial velocities of stars, clusters, and galaxies and stellar compositions. Advances in technology and increased awareness of the potential of spectroscopy in

7024) M. E. Schaepman, R. O. Green, S. G. Ungar, B. Curtiss, J. Boardman, A. J. Plaza, Bo-Cai Gao, S. Ustin, R. Kokaly, J. R. Miller, S. Jacquemoud, E. Ben-Dor, R. Clark, C. Davis, J. Dozier, D. G. Goodenough, D. Roberts, G. Swayze, E. J. Milton, A. F.H. Goetz, “The Future of Imaging Spectroscopy – Prospective Technologies and Applications,” Proceedings of IGARSS 2006 and 27th Canadian Symposium on Remote Sensing, Denver CO, USA, July 31–Aug. 4, 2006

the 1960s to 1980s lead to the first analytical methods and the inclusion of ‘additional’ bands in multispectral imagers.

At the start of the 21st century, technological advances in the domain of focal plane development, readout electronics, storage devices and optical designs, are leading to a significantly better sensing of the Earth’s surface. Improvements in signal–to–noise, finer bandwidths and spectral sampling combined with the goal of better understanding the modeled interaction of photons with matter will allow for more quantitative, direct and indirect identification of surface materials based on spectral properties from ground, air, and space.

Spectrum. Refers generally to the intensity distribution of electromagnetic radiation as a function of wavelength, wavenumber, or frequency.

Spread–spectrum technology. A transmission technique that allows multiple senders and receivers to share the same portion of the spectrum (bandwidth) by having each sender encode its transmission in a unique way decipherable by only its intended receiver. By spreading the RF energy across a range of frequencies, spread spectrum techniques improve a communication system’s noise rejection capabilities. Two basic techniques exist: a) FHSS (Frequency Hopping Spread Spectrum), and b) DSSS (Direct Sequence Spread Spectrum).

- The FHSS technique breaks the spectrum into many narrow channels; but instead of transmitting and receiving on just one of these the channels, the entire system “hops” from channel to channel in a predetermined order. This provides a resilient communication link whereby any communication that is blocked by interference on one channel will be retransmitted on a different channel. The FHSS technique is for instance advantageous for constellation support, providing the ability to communicate with and between multiple nearby satellites of the constellation. Also, the selection of hopping patterns makes it possible to avoid narrowband interference from RF devices near the ground station.
- DSSS achieves communication robustness in a different manner, namely by spreading the RF energy continuously over a wide bandwidth. The original data signal is mixed with a second signal that is much wider in frequency. The pattern of this second signal is called a chipping sequence and it is made up of a pseudorandom code (PRC). The PRC appears as noise to systems that don’t know the code. The resulting signal is as wide as the chipping sequence, but still carries the data that was contained in the original signal. By mixing the two signals together, the resulting transmission still looks like noise to any system that doesn’t know the chipping sequence. – The DSSS technique is for instance extensively being used for precise ranging, as is the case for GPS and the GLONASS ranging messages.

Spread spectrum technology is also used for wireless LANs that conform to the IEEE 802.11 and 802.11b standards as well as to PCS (Personal Communication Services) via satellite on such systems as ‘Iridium’ and ‘Globalstar.’ The 802.11 standard allows both FHSS and DSSS implementations to meet the standards requirements at speeds of up to 2 Mbit/s. The spread–spectrum technology allows communication satellites to capture and transmit signals that normally would be lost because the original signals were too weak or had too much interference. The wide bandwidth of the technology (about three orders of magnitude higher than normal radio frequencies) make it difficult to intercept the signal by an unauthorized party. The feature of low interception probability is attractive for many communication applications.

Squint. The term is used to describe an oblique pointing geometry of a sensor. For instance, a typical SAR pointing geometry is in the cross–track direction, normal to the flight path. Squinting occurs when the antenna beam is pointed forward or backward from this orthogonal direction.

Standing wave. A wave that is stationary with respect to the medium in which it is embedded, e.g., two equal gravity waves moving in opposite directions.

Station keeping. Refers to the maintenance of a geostationary satellite in its assigned orbital slot with regard to position and orientation (attitude). Orbital drifts are due to small gravitational effects of the sun and the moon as well as to an inhomogeneous Earth. The physical mechanism for station keeping is the controlled ejection of hydrazine (N_2H_4) gas by command from a control center.

Steradian (sr). A unit of solid angle measure in the International System, defined as the solid angle of a sphere subtended by a portion of the surface, whose area is equal to the square of the sphere's radius. The total solid angle about a point is 4π steradians. The term steradian is derived from the Greek for 'solid' and 'radian' – a steradian is, in effect, a solid radian.

Stereoscopy. The spatial three-dimensional or 'stereo' observation of related 2-D images, showing the same object under different viewing angles. Stereo images are very appropriate for map-making and for many other applications (flight simulators, etc.). The image combination of a target area may either result from, say, three cameras of an instrument pointing into the forward, nadir and aft directions, respectively, of a subsatellite track, or from a single gimballed camera, performing along-track imaging by pointing into the forward, nadir and aft directions successively. Stereo images offer better surface relief mapping capabilities than do regular 2-D images.

Store-and Forward (S&F). A non-real-time communication technique between a LEO satellite and its ground segment (often used for Data Collection Systems, e-mail systems, etc.). In this setup the originating ground station (or terminal) sends a digitized message to the LEO satellite; the satellite intermittently stores the message in an onboard storage system, and the destination ground station later receives the message when the satellite footprint is in its view. Multiple small satellites in polar LEO increase the message traffic capacity and reduce delivery delays.

Stovepipe application: A stovepipe application is designed for a specific purpose and built to run on an independent desktop computer. Most consumer end applications are stovepipe applications. Such an application is packaged, installed and deployed without requiring any add-on or external software utilities, regardless of integration.

A stovepipe application is in contrast to a distributed application, which is deployed and executed on various integrated software and systems and prevalent in environments that are highly prone to risk.

Stratopause. Stratosphere-mesosphere boundary (at about 50–55 km in altitude) where a relative temperature maxima is found (see Figure 1566).

Stratosphere. Region of the atmosphere between the troposphere and mesosphere, having a lower boundary of approximately 8 km at the poles and 18 km at the equator, and an upper boundary of approximately 50 km. Depending upon latitude and season, the temperature in the lower stratosphere can increase, be isothermal, or even decrease with altitude, but the temperature in the upper stratosphere generally increases with height due to absorption of solar radiation by ozone. – The importance of the stratosphere stems from the absorption of the bulk of the solar UV radiation, in particular in the wavelength regions of 290–320 nm. Penetration of this UV radiation to the Earth's surface may be harmful to life. The component in the stratosphere absorbing the bulk of the UV radiation is ozone (O_3).

Stray light. Refers to radiation not coming from the object of investigation (an unwanted radiation contribution detected by an instrument whose source is outside of the target volume or area). Stray light is often the major source of measurement uncertainty for commonly used spectrometers. It can cause unexpectedly large systematic errors, even as much as 100% depending upon the application, when an instrument tries to measure a very low level of radiation at some wavelength while there are relatively high levels in other wavelength regions.

As of 2005, NIST (National Institute of Standards and Technology, USA) researchers im-

plemented and validated the method using a commercial CCD–array spectrograph, which measures light in the visible region instantly. They characterized the response to monochromatic emissions from tunable lasers that covered the instrument’s full spectral range. Calculations were made using the measured data to produce a matrix that quantified the magnitude of the stray–light signal for every element (or pixel) of the detector array for every wavelength of light. The matrix then was used to correct the instrument’s output signals for stray light. The method is simple and fast enough to be incorporated into an instrument’s software to perform real–time stray–light corrections without much reduction in the instrument’s speed. ⁷⁰²⁵⁾

Strehl ratio: The Strehl ratio was introduced by the German physicist, mathematician and astronomer Karl Strehl at the end of 19th century (1864–1940). ⁷⁰²⁶⁾ By definition, the Strehl ratio is the ratio of peak diffraction intensities of an aberrated vs. a perfect wavefront. – The ratio indicates the level of image quality in the presence of wavefront aberrations; often times, it is used to define the maximum acceptable level of wavefront aberration for general observations – the so–called diffraction–limited level is conventionally set to 0.80 Strehl.

The modern definition of the Strehl ratio is the ratio of the observed peak intensity at the detection plane of a telescope or other imaging system from a point source compared to the theoretical maximum peak intensity of a perfect imaging system working at the diffraction limit. This is closely related to the sharpness criteria for optics defined by Karl Strehl. – For example: A Strehl ratio of 0.95 means that 95% of the theoretical maximum amount of light is going where it should go – and 5% of the light are lost to the surroundings, and contributing to a reduction in contrast. A Strehl ratio of 1 is equivalent to an absolutely perfect image. ⁷⁰²⁷⁾

The Strehl ratio is commonly used to assess the quality of seeing in the presence of atmospheric turbulence and assess the performance of any adaptive optical correction system. It is also used for the selection of short exposure images in the lucky imaging method. Without adaptive optics, the ratio for ground–based telescopes is less than 1%. The adaptive optics systems on other major telescopes today improve image quality up to about 30% to 50% in the near–infrared wavelengths.

Until relatively recently, ground–based telescopes had to live with wavefront distortion caused by the Earth’s atmosphere that significantly blurred the images of distant objects. ⁷⁰²⁸⁾ The **LBT** (Large Binocular Telescope), a ground–based telescope (consisting of two mirrors each with an aperture of 8.4 m) at the University of Arizona’s Steward Observatory, with next generation adaptive optics, is providing astronomers with a new level of image sharpness never before seen. In the initial testing phase (May 2010), the LBT’s adaptive optics system has been able to achieve unprecedented Strehl ratios of 60 to 80%, a nearly two–thirds improvement in image sharpness over other existing systems.

Subcarrier. Refers to a second signal “piggybacked” onto the main signal (carrier) to carry an information channel.

Sunspot. A temporary disturbed area in the solar photosphere that appears dark because it is cooler than surrounding areas. Sunspots are concentrations of strong magnetic flux (2000 – 3000 gauss), with diameters less than about 50,000 km and lifetimes of a few weeks.

Sun–synchronous orbit. On orbit is said to be sun–synchronous when the precessing rate of the orbital plane of a satellite, caused mostly by Earth flattening at the poles, is the same

⁷⁰²⁵⁾ “New NIST Method Improves Accuracy of Spectrometers,” June 16, 2005, URL: http://www.nist.gov/public_affairs/techbeat/tb2005_0616.htm

⁷⁰²⁶⁾ <http://www.telescope-optics.net/Strehl.htm>

⁷⁰²⁷⁾ http://en.wikipedia.org/wiki/Strehl_ratio

⁷⁰²⁸⁾ “Telescope Achieves Major Breakthrough Using Adaptive Optics,” Space Daily, June 17, 2010, URL: http://www.spacedaily.com/reports/Elescope_Achieves_Major_Breakthrough_Using_Adaptive_Optics_999.html

as the apparent motion of the sun in the celestial sphere, namely 0.9856° / day. Such an orbital configuration results in a (nearly) constant local time of ascending node (resulting in observations of a given area on the Earth's surface that are always made at the same local time of the day and the same solar incidence angle). – A sun–synchronous orbit is typically inclined by several degrees off the pole such that Earth's equatorial bulge acts to rotate the plane of the orbit around Earth, at a rate that matches the motion of the sun across the sky. See also chapter Q.10.1.

Superconducting Tunnel Junctions (STJs). Initially under development as efficient detectors of x–rays, they are now being used as single photon detectors in the visible spectrum. STJ (developed at ESA/ESTEC) operates in the range 200 – 1000 nm with a spectral resolution of 45 nm. Unlike a silicon–based CCD, the niobium–based STJ generates a number of electrons (in the thousands) that depends on the incoming photon's energy. This property eliminates the need for filters or diffraction gratings that lower the overall efficiency.

Superconductivity is the ability of a material to carry electricity with no resistance. Superconductivity was discovered in 1911 by Gilles Holst and Heike Kammerlingh–Onnes in their laboratory in Leiden, The Netherlands, just three years after they had succeeded in liquifying helium. Holst/Onnes discovered the abrupt and complete disappearance of resistance in certain metals when they were cooled below the critical temperature T_c of 4.2 K using liquid helium. [Note: instrumentation at liquid helium temperatures is referred to as LTS (Low Temperature Superconductivity) devices].

Superconductivity can be characterized by two physical properties: 1) zero direct current (DC) electrical resistivity; and 2) perfect diamagnetism (shielding of external, static magnetic fields).

The value of T_c has changed ever since. The search for a higher T_c began in particular in the 1980s to save the enormous cooling costs at cryogenic temperatures leading eventually to **HTS** (High Temperature Superconductivity). ^{7029) 7030)}

- $T_c = 35$ K (April 1986). Karl Alexander Müller and Johannes Georg Bednorz (IBM Research Laboratory, Switzerland) discovered superconductivity in $(\text{La–Ba})_2\text{CuO}_4$. In 1987, the Nobel Prize in physics was awarded to both researchers.
- $T_c = 77$ K (end of 1986). P. C. W. Chu (University of Texas at Houston) discovered superconductivity in the liquid–nitrogen temperature range.
- T_c above 90 K (January 1987). M. K. Wu, Chu's former student, achieved stable and reproducible superconductivity above 90 K in $\text{YBa}_2\text{Cu}_3\text{O}_7$ (YBCO), with T_c close to 93 K.
- $T_c = 110$ K and 125 K (1988) for bismuth and thallium superconducting systems respectively
- $T_c = 164$ K (1993) for mercury–based compounds under pressure (University of Texas, Houston).
- etc.

The first SQUID (Superconducting Quantum Interference Device) instrumentation appeared in 1964 and was widely used in the field of cryogenics. In the late 1980's, the discovery of high–temperature superconductor materials opened the possibility of introducing the technology in superconducting instruments. Commercial applications of HTS technology in fields such as electric power, transportation, electronics and medicine are appearing in the 1990s. Current applications of HTS include thin–film technology, magnetic resonance imaging (MRI), wireless communication filters, and ultra–fast computer chips. Modern

7029) Special issue: “Superconductivity,” Physics Today, March 1986

7030) A. P. Malozemoff, J. Mannhart, D. Scalapino, “High–Temperature Cuprate Superconductors Get to Work,” Physics Today, April 2005, pp. 41–47

discoveries in superconductivity go far beyond piece-meal improvements in electric devices. They have opened the door on a totally new technology and stretch the imagination to the discovery of new applications. The greatest commercial opportunity for HTS technology introduction is seen in electric power applications that require long lengths of wire. Also, HTS wires can support a rms current density of better than 100 A/mm^2 , a factor of 100 greater than the rms current density typically carried in the copper wires used in transmission cables.

Superresolution (or super-resolution) relates to image interpolation and reconstruction. Superresolution is the process of obtaining an image at a resolution higher than that afforded by the sensor used in the imaging. Superresolution deals with this issue by incorporating a priori information into the process of establishing an appropriate set of projections for reconstruction.

There are several complementary techniques to increase the apparent resolution of an image: a) sharpening, b) aggregation from multiple frames, and c) single-frame superresolution (not further discussed).

- Sharpening amplifies details that are present in the image.⁷⁰³¹⁾ In particular, it refers to the removal of blur caused by the imaging system (out of focus blur, motion blur, non-ideal sampling, etc.) as well as recovery of spatial frequency information beyond the diffraction limit of the optical system.
- Aggregation from multiple frames. The objective in this approach is to obtain a single high resolution image from several low resolution images (merging low resolution data onto a finer grid). Naturally, these images must be of the same object (target region) and must be taken from slightly different angles. Obviously, if successive frames are exact duplicates of one another, no new information is available, and no new information can be obtained. Successive images must be taken from slightly different perspectives, but not so much as to change the overall appearance of the object(s) in the image. Hence, the availability of **multistatic observation imagery** (examples: spotlight mode of observation, stereo imagery, interferometric SAR imagery) is definitely a promising approach to achieve superresolution by aggregation.

Since images are based on units of pixels, there are discrete steps in features such as object boundaries which will not be at the same pixel locations in successive frames. This, however, is the underlying feature permitting to extract more information than what is available in a single LR (Low-Resolution) image. The “overlay” of frames from different angles onto a reference frame requires a transformation from the LR to SR (Super-Resolution) frame. There are several superresolution methods in use:⁷⁰³²⁾

- Frequency domain reconstruction.
- Iterative methods
- Bayesian methods

Some background:⁷⁰³³⁾ All imaging systems have an upper limit on resolution. These limitations can arise in several ways:

- Diffraction of light limits resolution to the wavelength of the illuminating light
- Lenses in optical imaging systems may truncate the image spectrum in the frequency domain

7031) S. Borman, R. Stevenson, “Spatial Resolution Enhancement of Low-Resolution Image Sequences – A Comprehensive Review with Directions for Future Research,” July 8, 1998, <http://www.nd.edu/~sborman/publications/SRreview.pdf>

7032) R. Y. Tsai, T. S. Huang, “Multiframe Image Restoration and Registration, Chapter 7,” in *Advances in Computer Vision and Image Processing* (T. S. Huang, ed.), JAI Press Inc., 1984

7033) B. R. Hunt, “Super-Resolution of Imagery: Understanding the Basis for Recovery of Spatial Frequencies Beyond the Diffraction Limit,” http://www.eleceng.adelaide.edu.au/ieee/idc99/papers/hunt_bobby_2.pdf

- Sampling of images limits the maximum spatial frequency to a fraction of the sampling rate.

The diffraction of electromagnetic waves causes an optical system to behave as a low-pass filter in the formation of an image. Fourier optics demonstrates that there exists a cut-off spatial frequency, which is directly determined by the shape and size of the limiting pupil in the optical system. Beyond the diffraction limit cut-off frequency no spatial frequency information about the object is passed into the image. Within the passband of the optical system, i.e., from DC to the optical cut-off spatial frequency, this alteration of the spatial frequency components of the object is governed by the optical transfer function (OTF). This description of the Fourier nature of the image formation process is valid for imaging in both coherent and incoherent light. — Since the formation of an image alters the recorded information content from that of the original object, there has been much interest and effort directed to processing the image so as to more closely match the original object. In recent years it has become clear that there are credible methods for the reconstruction of spatial frequencies of the object that are greater than the diffraction limit spatial frequencies in the image. Processes that achieve the recreation of frequencies beyond the image passband are usually referred to as superresolution algorithms. The ability to achieve superresolution of an image is controversial, with prominent literature proclaiming it as not possible. However, the existence of algorithms that have demonstrated superresolution in a number of different contexts has made it inescapable to conclude that superresolution is possible. Understanding the basis of superresolution also leads to understanding how the various algorithms for superresolution function.⁷⁰³⁴⁾

Surface charge. A satellite immersed in an ambient plasma will come to equilibrium with that plasma by developing surface charges of the proper sign and magnitude to reduce the net current between the satellite and the ambient plasma to zero. The net current consists of a) currents from the environmental flux, b) secondary backscattered electrons and ions, and c) by photoelectrons from any illuminated areas on the spacecraft. As a result of these three processes contributing to the charged particle fluxes, a potential distribution exists about the spacecraft so that the net current to the satellite is zero. The potential distribution about a satellite may be rather asymmetric; this depends very much on the satellite geometry, it is also due to the anisotropic distribution of the particle fluxes.⁷⁰³⁵⁾

Surface roughness. Variation in surface height within an imaged resolution cell. A surface appears “rough” to microwave radiation when the height variations become larger than a fraction of the radar wavelength.

Synchronization (sync). Refers to the process of orienting the transmitter and receiver circuits in the proper manner in order that they can be synchronized. Usually a data format is preceded by a sync pattern which is recognized by the receiver.

Synoptic view. A large (inclusive) scene of the Earth’s surface, or of an object/target under investigation, allowing a large-scale overview of features or phenomena or relations of a scene in a wider context.

Swath. Width of the imaged scene in the range direction.

Technology Readiness Level (TRL). TRL is a measure used by NASA, by DoD (as well as by other space agencies in slightly varied form) to assess the maturity of evolving technologies (materials, components, devices, etc.) prior to incorporating that technology into a system or subsystem. Generally speaking, when a new technology is first invented or conceptualized, it is not suitable for immediate application. Instead, new technologies are usually subjected to experimentation, refinement, and increasingly realistic testing. Once the technology is sufficiently proven, it can be incorporated into a system/subsystem.

7034) H. C. Andrews, B. R. Hunt, “Digital Image Restoration, Prentice–Hall, Englewood Cliffs, NJ, 1976.

7035) E. A. Bering, III, R. Kabadi, B. McIntyre, “High Voltage Spacecraft Charging: Theory and Measurement,” Proceedings of the AIAA 2000 Space Conference and Exposition, Long Beach, CA, Sept. 19–21, 2000

Some background: The TRL methodology originated at NASA HQ in 1974. Then the scale progressed until 1995 with the definition of nine levels (Figure 1608). The principle of a maturity scale has been adopted by many companies and government agencies around the world. However, although they are somewhat similar, different definitions are used by different agencies.⁷⁰³⁶⁾

- In 2001, the American Deputy Under Secretary of Defense for Science and Technology issued a memorandum that endorsed the use of TRLs in new major U.S programs. U.S. government acquisition programs are now required to certify that Critical Technology Elements have been demonstrated in a relevant environment (TRL 6) at program initiation.
- In July 2005 at the “1st Symposium on Potentially Disruptive Technologies and their Impact in Space Programs” in Marseille (France), following a CNES initiative, ESA, NASA, JAXA and CNES decided to start coordination of the scale. At that time, JAXA was wishing to merge several level in one to simplify the process, ESA scale was with 8 levels, CNES and NASA/DOD were using 9 levels. The first step was to decide altogether to use 9 levels as presented in the “JC Mankins 1995 scale”.
- In order to avoid ambiguity and different interpretation and to guarantee a maximum accuracy when using this reference scale in international partnerships, The ECSS (European Cooperation for Space Standardization), decided, in 2009, to propose a New Work Item (NWI) to the International Organization for Standardization (ISO).

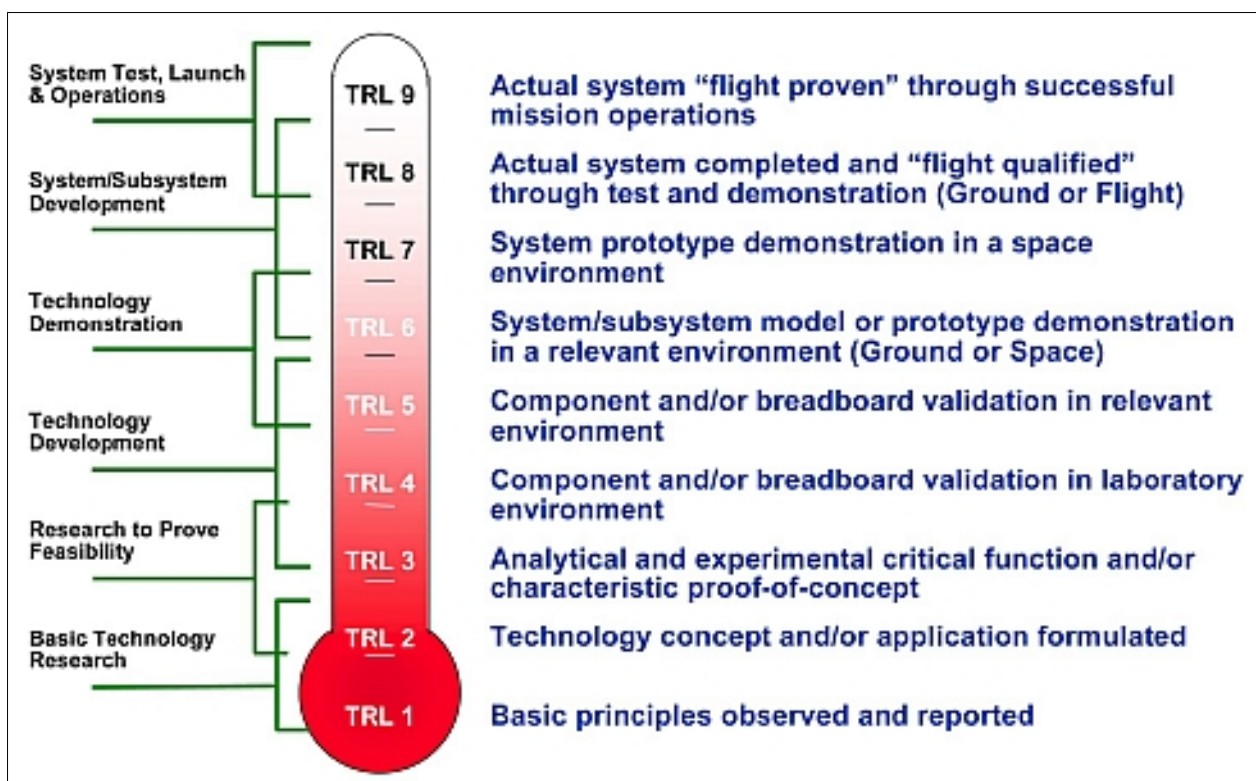


Figure 1608: Overview of NASA TRLs (Technology Readiness Levels), image credit: NASA

ECSS interpretation of levels 5 and 6: For ECSS, level 5 is reached when the critical functions of the element are validated in the relevant environment. For that purpose, a flight representative model(s) in terms of form, fit and function is used for unambiguously demonstrating the element performance. The test performance is in agreement with analytical predictions. The model(s) demonstrate(s) the performance of the element as a whole

⁷⁰³⁶⁾ Franck Durand–Carrier, Geilson Loureiro, “Standardization of the Technical Readiness Levels (TRL),” Proceedings of IAC 2011 (62nd International Astronautical Congress), Cape Town, South Africa, Oct. 3–7, 2011, paper: IAC–11–D1.3.12

with its different components functioning in an integrated manner.

Then, level 6 requires the verification of the element performance through qualification testing to demonstrate performance in the operational environment. For that purpose, a qualification model or prototype of the element is built, reflecting all aspects of the operational system design. Qualification tests are defined properly covering the performance verification needs, including margins. This level is generally reached in the framework of a specific program.

US interpretation of levels 5 and 6: For US agencies, level 5 is reached when the critical functions of the element are demonstrated in the relevant environment using appropriate breadboards, which are generally not full scale or full function. The test performance is in agreement with analytical predictions however scaling factors have still to be demonstrated. Level 6 is similar to the one identified as level 5 by ECSS. Then qualification testing, based on a qualification model or prototype, generally done also in the framework of a specific program, is included in the level 8 recognized by everyone as reaching the “flight qualified” status (final system ready to be flown).

- Agreement on level definitions: For the US side it was very important to keep its interpretation of level 6 as it is considered as “the gateway to a program”. For the ECSS side it was very important to clearly identify an intermediate level for “qualification testing” before level 8.

The consensus was reached by keeping level 6 as interpreted by the US, and by introducing a new level 7 (replacing the old one) defined as ECSS was interpreting the level 6. This consensus was the way to have a chance to internationally standardize the TRL.

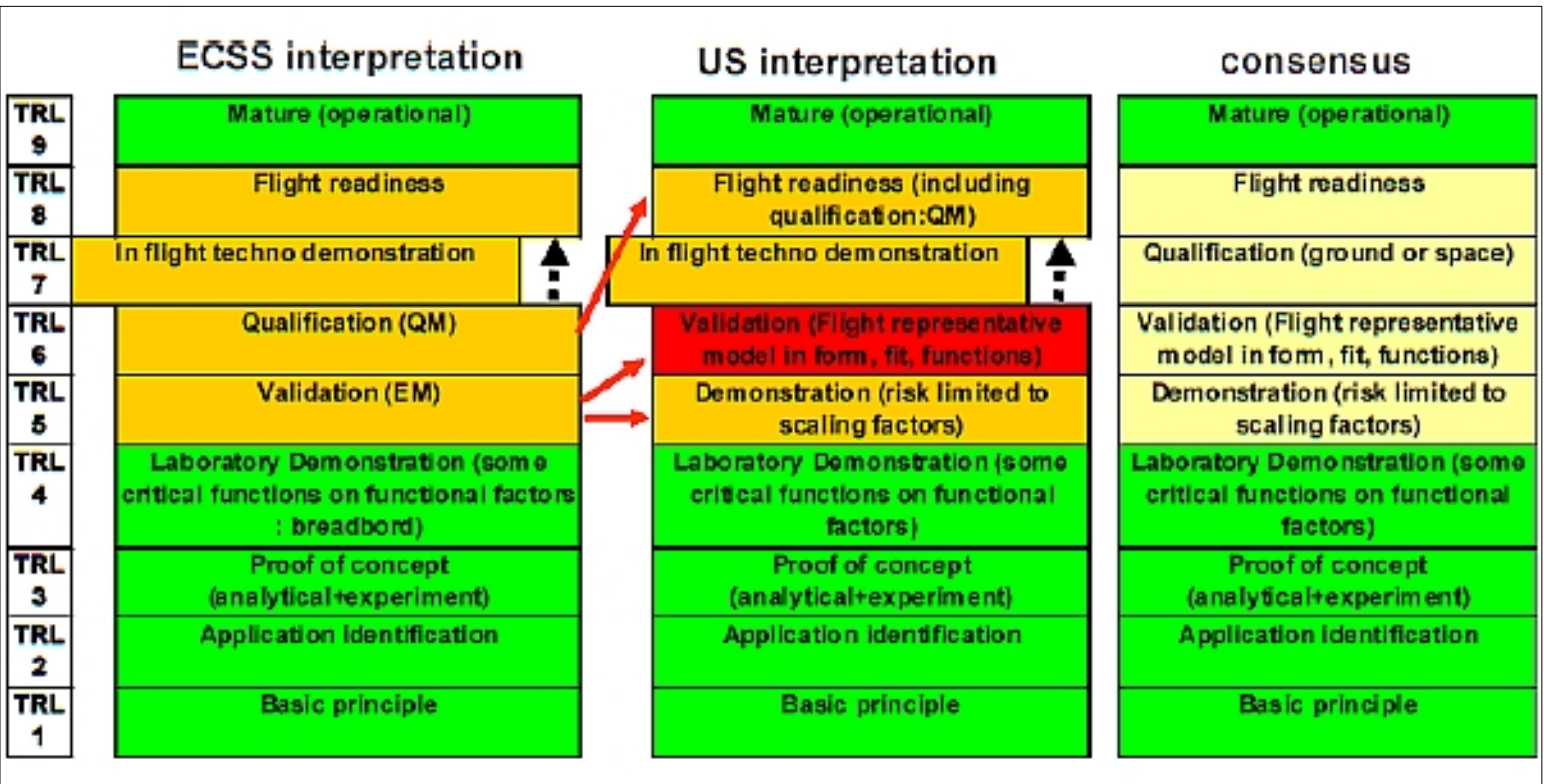


Figure 1609: Proposed consensus for TRL scale (image credit: CNES, INPE)

- ISO FDIS 16290: The ISO FDIS (Final Draft International Standard) 16290 “Definition of the Technology Readiness Levels (TRLs) and their criteria of assessment” will be

published in late 2013. ⁷⁰³⁷⁾

Telemetry. A space-to-ground data stream of measured values (normally including instrument science data, instrument engineering data, and spacecraft engineering data) that does not include commands, tracking, computer memory transfer, audio, or video signals.

Telemetry, Tracking and Command (TT&C). Refers to the function of spacecraft operations (monitoring and control of all vital system parameters and tracking of the orbit) by a control center. These TT&C functions are normally completely separate from the spacecraft's user signal (communication satellite) or the measured source (or instrument) data (in case of an Earth observation satellite). Hence, they are also transmitted in a separate band. – The TT&C link is the umbilical cord of a mission: the success of a mission heavily depends on its reliability and performance. Every single mission (science, earth observation, telecom, ..) has a TT&C link, although with quite different requirements.

Telescience. A technique referring to the control of scientific and/or engineering experiments/instruments from a remote location. Applications include various configurations such as Earth–Earth connections as well as Earth–spaceborne support.

Telescopes (types). Optical telescopes are of two basic types, refractors or reflectors that use lenses or mirrors, respectively, for their light collecting elements. The Galilean (1564–1642) and Keplerian (1571–1630) telescopes are of the refractive type. The Cassegrain and Gregory telescopes are of the reflective type. Reflectors are used in the UV, VIS and IR regions of the electromagnetic spectrum. The name of this type of instrument is derived from the fact that the primary mirror reflects the light back to a focus instead of refracting it. The following list mentions only a few telescope designs (employed in EO).

- **Cassegrain telescope** (design was proposed in 1672 by Guillaume Cassegrain, a French scientist). A reflective telescope in which a small hyperboloidal secondary mirror reflects the convergent beam from the paraboloidal primary mirror through a hole in the primary mirror to an eyepiece in back of the primary mirror (see also Cassegrain antenna). The Cassegrain telescope design is the most frequently used two-mirror system.
- **Dall–Kirkham telescope.** Invented by the master optician Horace E. Dall in 1928 of Luton, England. A Cassegrain-type instrument where the primary mirror geometry is an ellipse, while the secondary mirror is a sphere. The advantage of the Dall–Kirkham design lies in that the spherical secondary is fundamentally easier to construct. However, the design does not correct for comatic off axis images.
- **Ritchey–Chrétien telescope.** Designed in Paris by the American astronomer George W. Ritchey (1864–1945) and the French physicist (optics) Henri Chrétien (1879–1956), in 1927. The Ritchey–Chrétien telescope is a Cassegrain-type instrument. The telescope design reduces the ‘coma’ (image aberrations) by modifying the primary and secondary surfaces of a Cassegrain telescope. The Ritchey–Chrétien telescope employs a hyperboloidal figure for both the primary and secondary mirror thereby providing excellent resolution over a large FOV. Simply stated, the Ritchey–Chrétien telescope design has the largest, aberration-free field of view, of any reflecting telescope.
- **Gregorian telescope.** In 1663, James Gregory (a 17th century Scottish mathematician) invented the first reflecting telescope using an arrangement of two concave mirrors. Gregory placed a concave secondary mirror outside the prime focus to reflect the light back through a hole in the primary mirror. The spacecraft of the SMM (Solar Maximum Mission), launched in 1980, flies a Gregorian telescope.
- **Newtonian telescope.** Invented by Isaac Newton (1642–1727), English physicist and mathematician, in 1668. The primary mirror is of parabolic geometry; the secondary mirror

⁷⁰³⁷⁾ Franck Durand–Carrier, Geilson Loureiro, “The new ISO standard on TRL,” Proceedings of the 64th International Astronautical Congress (IAC 2013), Beijing, China, Sept. 23–27, 2013, paper: IAC–13–D1.3.2

may be a flat plat or a refractive prism. The light beam is diverted to one side for observa- tion.

Type of Telescope	Primary Optic	Secondary Optic	Configuration 1 – Primary Optic 2 – Secondary Optic 3 – Eyepieces/Correctors 4 – Focus (usually also the image plane)
Newtonian Examples: ALF, UV-DIAL	Parabola	Diagonal Flat	
Gregorian Example: UVSP	Parabola	Ellipse	
Cassegrain Ex: ALISSA, GOMOS, ALEX	Parabola	Hyperbola	
Dall-Kirkham Ex: CAR, CAMS, LASE, MCR	Ellipse	Sphere	
Ritchey-Chrétien Ex: SEVIRI, EIT, LEANDRE	Modified Para- bola	Modified Hyper- bola	
Schmidt Ex: LFS, OLS, HYDICE SPOT	Aspherical Refrac- tor	Sphere	

Figure 1610: Basic optical configurations for common types of reflective telescopes

- **Schmidt-Cassegrain telescope.** Bernhard V. Schmidt (1879–1935), an astronomer of Estonia. In 1930, Bernhard V. Schmidt of the Hamburg Observatory in Bergedorf, Germany, designed a catadioptric telescope with a large FOV to eliminate image distortions (a catadioptric telescope design incorporates the best features of both the refractor and reflector, i.e., it has both reflective and refractive optics). This design compensates for most of the spherical aberration by means of an aspherical refractor at the center of curvature. – Schmidt added in effect a correcting plate (a lens) to the conventional Cassegrain telescope, thereby creating the Schmidt-Cassegrain telescope which minimized the spherical aberration of the Cassegrain telescope.

Type of Image Defect	Description
Spherical aberration	Light focuses at different places along the optical axis as a function of radial position
Coma	Image size (magnification) varies with radial position in the focal region.
Field curvature	Off-axis images are not focused on the ideal surface, usually a plane
Astigmatism	Light focuses at different places along the optical axis as a function of angular position in the aperture

Type of Image Defect	Description
Distortion	Focused off-axis image is closer or further from the optical axis than intended
Chromatic aberration	Shift in the focused image position as a function of wavelength

Table 979: Definition of some basic image aberrations occurring in telescopes

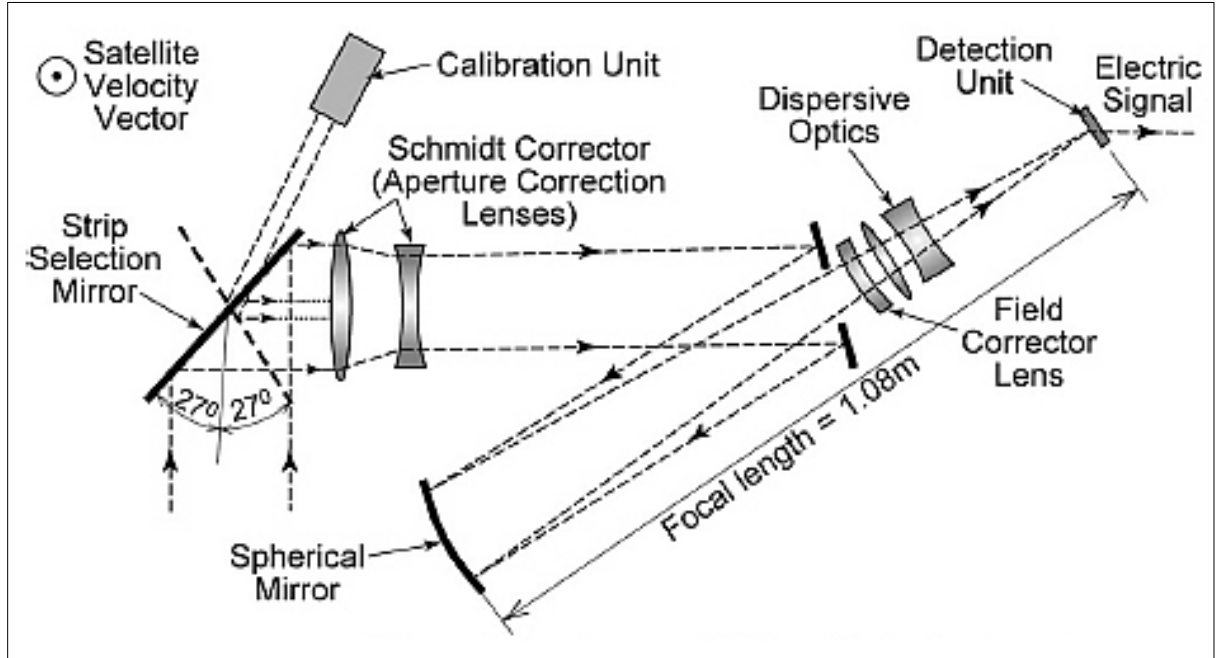


Figure 1611: Diagram of the Schmidt telescope as flown on the SPOT series satellites (image credit: CNES)

In the case of the original SPOT satellite series, a fairly simple form of the classical type of Schmidt telescope has been used (Figure 1611). This comprises a single spherical mirror with a focal length (f) of 1.08 m; a corrector plate mounted at the entrance aperture of the telescope; a flat plate mirror to allow folding of the path between the aperture and the spherical mirror; and a field correction lens and dispersive optics located in front of the focal plane with its CCD detectors.⁷⁰³⁸⁾

By contrast, the Pleiades series telescope of CNES employs a much more sophisticated design (Figure 1612). This takes the form of a highly folded Korsch-type three-mirror anastigmatic (TMA) telescope that produces excellent correction of geometric aberrations without the need for additional correction optics. This TMA telescope comprises three curved mirrors: a) a large concave primary mirror with an aperture of 650 mm; b) a convex secondary mirror; and c) a concave tertiary mirror – combined with a flat plane extraction mirror to allow a further folding of the optical path to be implemented. The launch of the first Pleiades spacecraft is scheduled for 2010.

⁷⁰³⁸⁾ Gordon Petrie, William E. Stoney, "The Current Status and Future Direction of Spaceborne Remote Sensing Platforms and Imaging Systems," ASPRS Manual of Remote Sensing, Chapter 9, pp. 279–339, 2009

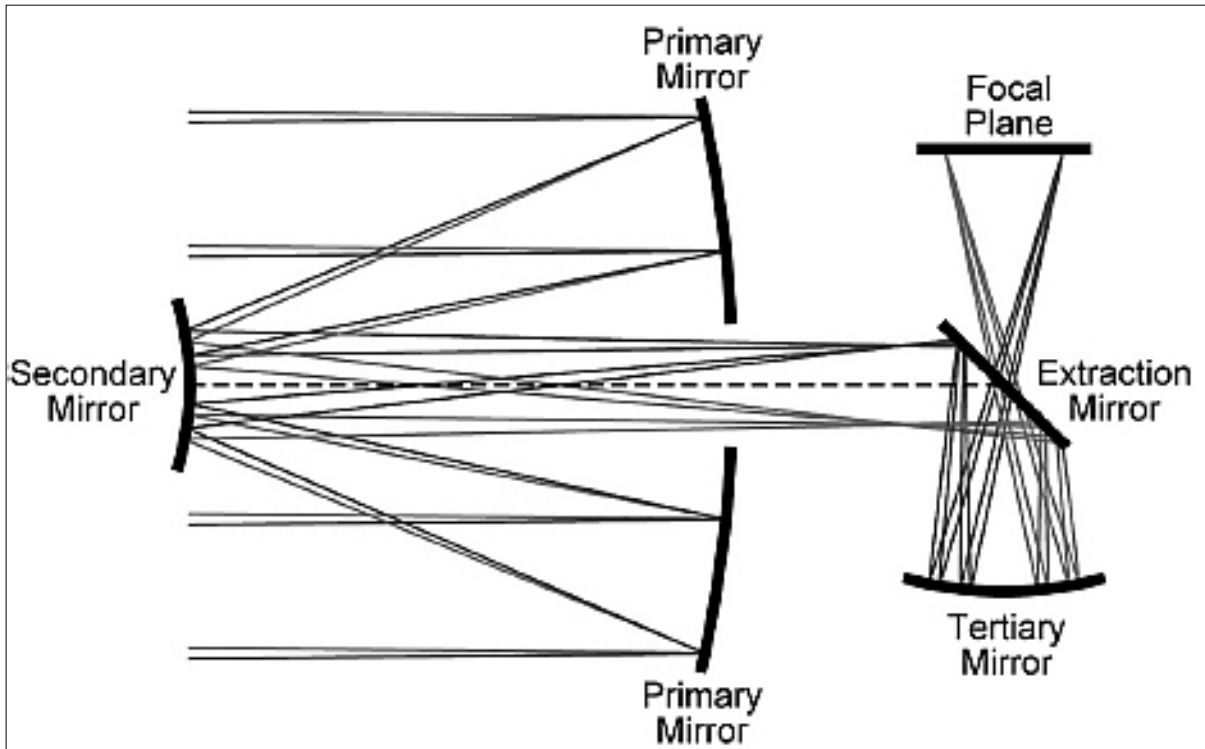


Figure 1612: Diagram of the Korsch TMA telescope for the Pleiades series satellites (image credit: CNES)

Terrestrial Gamma-ray Flash (TGF): TGFs are transient events (on the order of milliseconds) in Earth's atmosphere above thunderstorms, first recorded from the Compton Gamma Ray Observatory (CGRO) satellite of NASA in 1994. BATSE (Burst And Transient Source Experiment), an instrument on CGRO, studied the phenomenon of gamma-ray bursts, although the detectors also recorded data from pulsars, TGFs, soft gamma repeaters, black holes, and other exotic astrophysical objects. TGFs have been recorded to last 0.2–3.5 ms and have energies of up to 20 MeV. ^{7039) 7040)}

The newer RHESSI satellite of NASA (launch on Feb. 5, 2002) has observed TGFs with much higher energies than those recorded by BATSE. In addition, the new observations show that approximately 50 TGFs occur each day, larger than previously thought but still only representing a very small fraction of the total lightning on Earth (3–4 million lightning events per day on average). However, the number may be much higher than that due to the possibility of flashes in the form of narrow beams that would be difficult to detect, or the possibility that a large number of TGFs may be generated at altitudes too low for the gamma-rays to escape the atmosphere. ⁷⁰⁴¹⁾

The most frequently discussed mechanism of TGFs assumes gamma-ray production by gigantic upward atmospheric discharges (UADs) originating from the electrical breakdown driven by relativistic runaway electrons. NASA's Fermi Gamma-ray Space Telescope (launch June 11, 2008) carries the GBM (Gamma-ray Burst Monitor). The GBM constantly monitors the entire celestial sky above and the Earth below. In early 2011, the GBM team has detected beams of antimatter produced above thunderstorms on Earth, a phenomenon never seen before. ⁷⁰⁴²⁾

7039) <http://www.batse.msfc.nasa.gov/batse/tgf/>

7040) <http://www.answers.com/topic/terrestrial-gamma-ray-flash>

7041) David M. Smith, Liliana I. Lopez, R. P. Lin, Christopher P. Barrington-Leigh, "Terrestrial Gamma-Ray Flashes Observed up to 20 MeV," *Science* 18 February 2005, Vol. 307, No. 5712, pp. 1085 – 1088

7042) Tony Phillips, "Thunderstorms make antimatter," NASA, January 11, 2010, URL: http://science.nasa.gov/science-news/science-at-nasa/2010/11jan_antimatter/

In 2012, improved data analysis techniques and a new operating mode in the GBM resulted in a much better (10 times) catching the brief outbursts of high-energy light mysteriously produced above thunderstorms. ⁷⁰⁴³⁾

Theodolite. A surveying instrument used to measure horizontal and vertical angles.

Thermal control system. An onboard system which maintains all satellite components within allowable temperature limits for all operating modes of the satellite when exposed to the varying thermal environments throughout its lifetime. Typical thermal loads (forms of environmental heating) are: a) direct solar radiation, b) reflected radiation from the Earth's albedo, c) emission of long-wave IR radiation from the Earth, d) free molecular heating, and e) charged particle heating.

Thermal Infrared (TIR). Electromagnetic radiation in the spectral range of 6–20 μm . Many remote sensing applications utilize the 6–14 μm range (atmospheric window). TIR is emitted energy, whereas NIR (Near Infrared) is reflected energy.

Thermal noise. The 'noisy' detector signal of an infrared sensor caused by the thermal heating of the detector itself. Thermal noise occurs when the system is not sufficiently cooled.

Thermistor. A semiconductor device (sensor) whose electrical resistance varies with temperature. Its temperature coefficient of resistance is high, nonlinear, and usually negative.

Thermoluminescence. A property of certain minerals which causes them to emit light when moderately heated, after electrons are excited into traps by ionizing radiation.

Thermosphere. Outermost layer of the atmosphere, above the mesosphere.

Thin-film technology. Thin films are an important ingredient in all surface technology applications. Surfaces play an important role in nature as well as in technology where small-scale exchange processes take place. Nanotechnology offers a new realm for surface technology in which to operate, providing also new analytical methods for much clearer windows onto nanoscale surface structures. In solar cell applications, thin-film technology refers to dielectric layers for optical anti-reflective coatings, electrical passivation and diffusion barriers. Applications of thin-film technology abound in such fields as: lithography, deposition, etching, epitaxy, diffusion, optics, sensor technology, etc.

Thunderstorm activity: About 2000 thunderstorms are permanently active throughout the world, producing 50–100 lightning bolts per second. ⁷⁰⁴⁴⁾

Time Delay Integration (TDI): TDI is an imaging technique, a cumulative exposure concept for CCD imaging which integrates a pixel's electron charges to suppress the readout noise.

- The TDI imaging technology enables high-speed in-line AOI (Automatic Optical Inspection) of high-performance displays such as those used in iPhones, iPads and high-definition televisions. ⁷⁰⁴⁵⁾
- CCD TDI is a special type of line-scan technology based on multiple exposures of the same moving object to achieve higher responsivity. In TDI operation, the speed at which a charge packet containing image data is transferred within the CCD is in sync with the speed of the moving object, allowing the data packet to track the motion of the object. Photogenerated electrons are transferred from one TDI stage to another in the charge domain. The

7043) Francis Reddy, "Fermi Improves its Vision for Thunderstorm Gamma-Ray Flashes," NASA, Dec. 06.2012, URL: http://www.nasa.gov/mission_pages/GL&ST/news/vision-improve.html

7044) V. Pilipenko, New physical phenomena in the atmospheric lightning discharges: observations from microsattellites and ground, URL: http://www.kpk.gov.pl/pliki/10346/Pilipenko_New_physical_phenomena_in_the_atmospheric_lightning_discharges.pdf

7045) Xing-Fei He, Nixon O, "Time Delay Integration Speeds Up Imaging," Photonics Spectra, May 2, 2012, URL: http://www.teledynedalsa.com/public/mv/appnotes/TDI_Speeds_Up_Imaging-Photonics_Spectra_May2012.pdf

transfer is accomplished without adding any noise. Because the detector signal is proportional to the number of stages, the SNR (Signal-to-Noise Ratio) scales linearly with the number of stages.

Time Division Multiple Access (TDMA). A process that shares the time domain of a single carrier among many users by assigning to each time intervals in which to transmit signal bursts. In this scheme, all users transmit on the same frequency, each is assigned the total available bandwidth for a limited amount of time. TDMA systems segment time into frames, each frame is further partitioned into assignable time slots.

Timekeeping. Precision timekeeping is one of the bedrock technologies of modern science and technology. It underpins precise navigation on Earth and in deep space, synchronization of broadband data streams, precision measurements of motion, forces and fields, and tests of the constancy of the laws of nature over time. ^{7046) 7047)}

Tomography (optical tomography).⁷⁰⁴⁸⁾ A diagnostic technique permitting the mathematical reconstruction of 3-D images from a set of 2-D measurements. Typical applications are the medical CAT (Computer Aided Tomography) scans which yield the structure of a human body from a set of X-rays. The tomography technique is also finding its way into high-speed applications (high temporal resolution), such as in aero-optical measurements of dynamic turbulent media (simultaneous measurements of the flow field and the optical field provide information of the flow structure in space and time). An application of this technique is the study of phenomena causing degradations in laser beam propagation through atmospheric boundary layer turbulence. In laser transmissions through turbulent media, adaptive optics systems are being used to correct for phase distortion. Adaptive optics systems rely on accurate measurements of the turbulent media and on its ability to distort the beam.

Naturally, the **microwave region** of the spectrum may also be used for tomographic studies/observations. For instance, the basic concept in CIT (Computerized Ionospheric Tomography) research is to use LEO satellites as moving transmitters and an array of ground receivers to measure TEC (Total Electron Content) in the ionosphere. Of course, TEC measurements can also be obtained from dual-frequency GPS observations (L1 and L2) taking advantage of the dispersive nature of the ionospheric medium (the equivalent vertical TEC value can be evaluated from the slant path GPS observations).

Total Electron Content (TEC). Refers to a count of the number of electrons in a vertical column stretching through the ionosphere with a cross-sectional area of 1 m^2 measured in TECU (Total Electron Content Unit). $1 \text{ TECU} = 10^{16} \text{ electrons m}^{-2}$ and corresponds to 16.3 cm of ionospheric delay at the L1 frequency of GPS.

Total Solar Irradiance (TSI).⁷⁰⁴⁹⁾ The total solar irradiance along with Earth's global average albedo determines Earth's global average equilibrium temperature. Because of selective absorption and scattering processes in the Earth's atmosphere, different regions of the solar spectrum affect Earth's climate in distinct ways. To place the 11-year sun cycle into perspective, the sun's **TSI is about 1367 Wm^{-2} in space** (i.e. in low Earth orbits of spacecraft). Since the intercepted radiation is distributed over the surface of the Earth, the average solar radiation at the top of the atmosphere is 1/4 of this, or about 340 Wm^{-2} ; hence, a

7046) "Blackbody energy set the stage for clocks with unprecedented accuracy," Space Daily, May, 16, 2011, URL: http://www.spacedaily.com/reports/New_calculations_on_blackbody_energy_set_the_stage_for_clocks_with_unprecedented_accuracy_999.html

7047) M. Safronova, M. Kozlov, C.W. Clark, "Precision Calculation of Blackbody Radiation Shifts for Metrology at the 18th Decimal Place," CLEO (Conference on Lasers and Electro-Optics) 2011, Baltimore, MD, USA, May 1-6, 2011, paper CFC 3

7048) Note: Tomographic methods were first formulated in the 1970s as a means of remotely mapping inaccessible regions of the human body.

7049) G. C. Reid, "Solar Variability and the Earth's Climate: Introduction and Overview," pp. 1-11 in Solar Variability and Climate, Editors: E. Friis-Christensen, C. Fröhlich, J. D. Haigh, M. Schüssler and R. von Steiger, Kluwer Academic Publishers, ISBN 0-7923-6741-3, 2000

variation of 0.1% corresponds to 0.34 Wm^{-2} . Planetary albedo scattering reduces this further to about 0.24 Wm^{-2} (approximately 20–25 % of the TSI is absorbed by atmospheric water vapor, clouds, and ozone, by processes that are strongly wavelength dependent. Ultraviolet radiation at wavelengths below 300 nm is completely absorbed by the Earth's atmosphere and contributes the dominant energy source in the stratosphere and thermosphere, establishing the upper atmosphere's temperature, structure, composition, and dynamics). Even small variations in the sun's radiation at these short wavelengths lead to corresponding changes in atmospheric chemistry. Radiation at the longer visible and infrared wavelengths penetrates into the lower atmosphere, where the portion not reflected is partitioned between the troposphere and the Earth's surface, and becomes a dominant term in the global energy balance and an essential determinant of atmospheric stability and convection. Thus it is important to accurately monitor both the TSI and its spectral dependence. 7050)

Trace gas. A minor constituent of the atmosphere. The most important trace gases contributing to the greenhouse effect are water vapor, carbon dioxide, ozone, methane, nitrous oxide, and chlorofluorocarbons. Other trace gases include ammonia, nitric oxide, ethylene, sulfur dioxide, methyl chloride, carbon monoxide, and carbon tetrachloride.

Tracking system. Tracking is the process of following a moving object. Tracking system is a general name for an apparatus, such as a tracking radar, used to follow and record the position of objects (airborne or spaceborne). A theodolite and an observer form, for instance, an optical tracking system which is used in pilot balloon runs.

Transceiver. A term made up of the words 'transmitter' and 'receiver' of a signal transmission system. Since each side of a two-way system requires both functions, they are provided in one unit.

Transient Luminous Events (TLEs): TLEs are high-altitude luminous flashes (large-scale transient phenomena) that take place above thunderstorms in a part of the atmosphere called the mesosphere. Typically the upper parts of clouds are charged positively and the lower parts negatively. These brief optical emissions (TLEs) are generally referred to as **sprites**.

Although cloud-to-ground lightning is a familiar disruption in the modern electronic world, lightning formed above the clouds is also an important factor in what is known as the '*global circuit of atmospheric electricity*'. Radio atmospheric emissions from lightning discharges and can propagate thousands of kilometers through the 'waveguide' formed by the Earth's surface and the ionized region of the upper atmosphere, known as the ionosphere. 7051)

Sprites constitute a wide range of optical and electromagnetic phenomena, which occur above the tops of active thunderclouds up to heights of 50–90 km. 7052) 7053) Although rather common and visible to the naked eye under the right viewing conditions, TLEs were not observed or accounted for, except, perhaps, in reports of high flying pilots. Sprites have been nicknamed by their appearance as red sprites, elves, blue jets, gigantic jets, halos, TGFs, etc.

In the 1920s, the Scottish physicist C. T. R. Wilson predicted the existence of brief flashes of light high above large thunderstorms. Almost 70 years later, Bernard Vonnegut of SUNY (State University of New York) Albany realized that evidence for Wilson's then unconfirmed predictions might appear in video imagery of Earth's upper atmosphere recorded by

7050) <http://lasp.colorado.edu/sorce/>

7051) Victor. P. Pasko, "Electric Jets," *Nature*, Vol. 423, No 26, June 2003, pp. 927–929, doi:10.1038/423927a

7052) W. A. Lyons, T. E. Nelson, A. Faires, "Electrical Discharges into the Stratosphere from the Tops of Intense Thunderstorms," AGU Fall Meeting, San Francisco, 2001, paper. AE22A-002.

7053) H. T. Su, R. R. Hsu, A. B. Chen, Y. C. Wang, W. S. Hsiao, W. C. Lai, L. C. Lee, M. Sato, H. Fukunishi, "Gigantic jets between a thundercloud and the ionosphere," *Nature*, Vol. 423, No 26, June 2003, pp. 974–976

space shuttle astronauts. He encouraged NASA's William Boeck and Otha Vaughan to look for evidence. The scientific evidence of sprites was accidentally recorded using a low-light level camera by R. C. Franz et al. of the University of Minnesota (reported in 1990) on the night of Sept. 22 1989. ^{7054) 7055)}

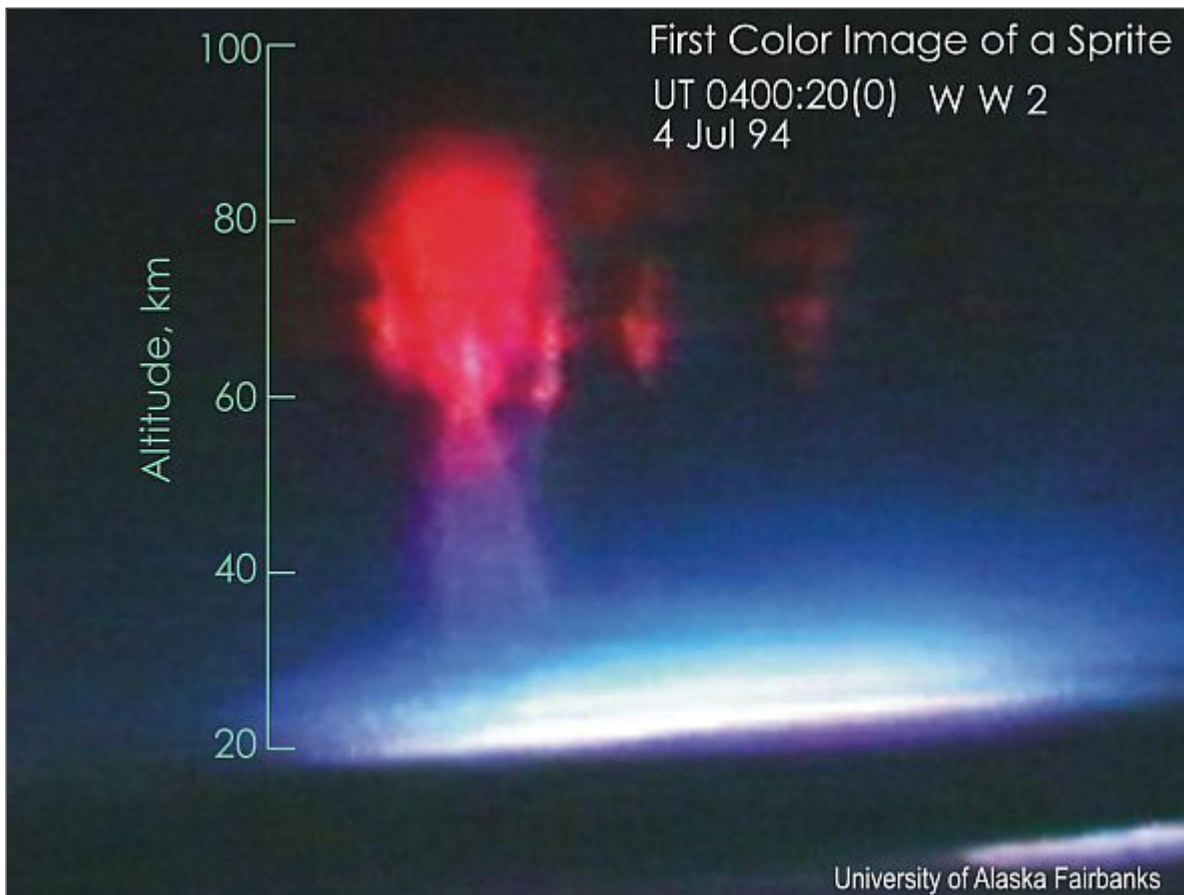


Figure 1613: The first color image of a sprite captured on camera on July 4, 1994 (image credit: University of Alaska) ⁷⁰⁵⁶⁾

May 2014: Atmospheric sprites have been known for nearly a century, but their origins were a mystery. Now, a team of researchers has evidence that sprites form at plasma irregularities and may be useful in remote sensing of the lower ionosphere. ^{7057) 7058)}

Sprites are an optical phenomenon that occur above thunderstorms in the D-region of the ionosphere, the area of the atmosphere just above the dense lower atmosphere, about 60–90 km above the Earth. The ionosphere is important because it facilitates the long distance radio communication and any disturbances in the ionosphere can affect radio transmission.

Sprites resemble reddish orange jellyfish with bluish filamentary tendrils hanging down below. Careful examination of videos of sprites forming showed that their downward hanging

7054) Earle R. Williams, "Sprites, elves, and glow discharge tubes," Nov. 2001, *Physics Today*, Vol. 54, 11, doi: 10.1063/1.1428435, URL: <http://scitation.aip.org/content/aip/magazine/physicstoday/article/54/11/10.1063/1.1428435?type=PTPICKS>

7055) R. C. Franz, R. J. Nemzek, J. R. Winckler, "Television Image of a Large Upward Electrical Discharge Above a Thunderstorm System," *Science*, Vol. 249, pp. 48–50, 1990.

7056) Jason Major, "On the Hunt for High-Speed Sprites," *Universe Today*, Aug. 23, 2012, URL: <http://www.universe-today.com/96984/on-the-hunt-for-high-speed-sprites/>

7057) ianqi Qin, Victor P. Pasko, Matthew G. McHarg, Hans C. Stenbaek-Nielsen, "Plasma irregularities in the D-region ionosphere in association with sprite streamer initiation," *Nature Communications*, Vol. 5, Article number: 3740, May 7, 2014, doi:10.1038/ncomms4740

7058) Andrea Elyse Messer, "Sprites form at plasma irregularities in the lower ionosphere," *Penn State News*, May 7, 2014, URL: <http://news.psu.edu/story/314975/2014/05/07/research/sprites-form-plasma-irregularities-lower-ionosphere>

filaments form much more rapidly than in the horizontal spread, leading the researchers to suggest that localized plasma irregularities cause the streamers to propagate.

A research team of Penn State University, USAFA, and the University of Alaska used a two-dimensional cylindrical symmetric plasma fluid model, a mathematical model of the ionization movements in the sprite, to study sprite dynamics. They then used the model to recreate optical sprite creation. From this recreation, the researchers determined where the sprite streamers originated, and they could estimate the size of the plasma irregularity.

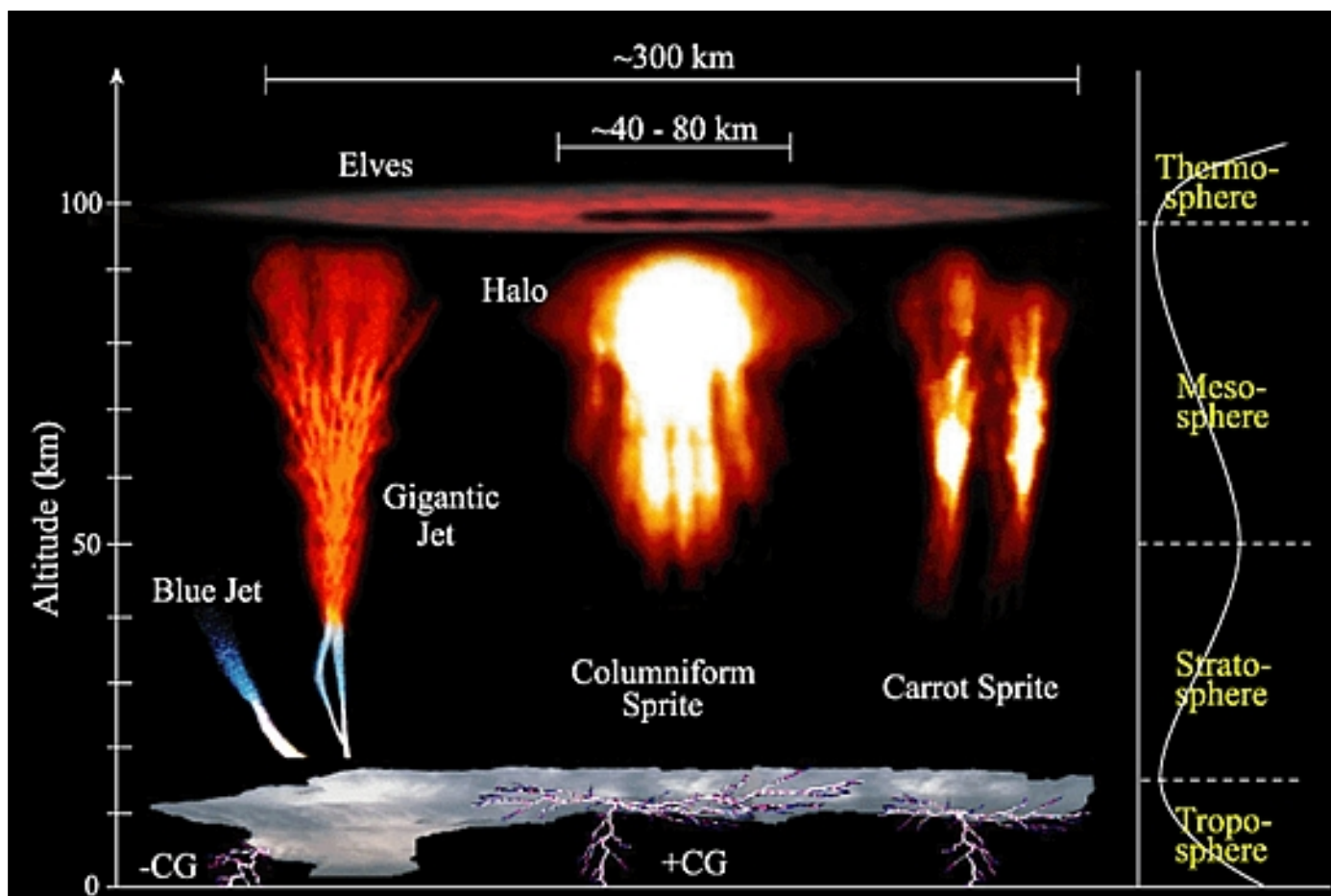


Figure 1614: Artist's rendition of various TLE types in the upper atmosphere (image credit: AGU, S. Nielson, et al.)

Since the discovery of TLEs, they were photographed from ground stations, aircraft, in balloon campaigns, the Space Shuttle, and other spacecraft. Some early examples are:

- The Sprites 1999 balloon campaign, funded by NASA, included the collaboration of three institutions: the University of Houston, the University of Alaska, Fairbanks, and FMA Research, Inc., Fort Collins, CO. ^{7059) 7060) 7061)} The campaign involved simultaneous observations of the sprites by instruments on the balloon and by observers at three ground stations. Three ground observing stations were located at Yucca Ridge Field Station, Ft. Collins, Colorado; Wyoming Infrared Observatory on Jelm Mt., Wyoming and Bear Mt. Fire Lookout in South Dakota. Three high-altitude balloon flights took place, one from Palestine (June 7, 1999), Texas, and two from Ottumwa, Iowa, USA (Aug. 15 and 21, 1999).

⁷⁰⁵⁹⁾ <http://www.uh.edu/research/spg/Sprites99.html>

⁷⁰⁶⁰⁾ E. A. Bering III, L. Bhusal, J. R. Benbrook, J. A. Garrett, A. M. Paredes, E. M. Wescott, D. R. Moudry, D. D. Sentman, H. C. Stenbaek-Nielsen, W. A. Lyons, "Transient Luminous Events Statistics, Source Strength Energetics during the 1999 Sprites Balloon Campaign," URL: <http://www.ursi.org/Proceedings/ProcGA02/papers/p0721.pdf>

⁷⁰⁶¹⁾ E. A. Bering III, L. Bhusal, J. R. Benbrook, J. A. Garrett, A. M. Paredes, E. M. Wescott, D. R. Moudry, D. D. Sentman, H. C. Stenbaek-Nielsen, W. A. Lyons, "The results from the 1999 sprites balloon campaign," *Advances in Space Research*, Vol. 34, Issue 8, 2004, Pages 1782–1791

– The MEIDEX (Mediterranean Israeli Dust Experiment), a radiometric camera with six narrow band filters and boresighted with a wide-FOV color video camera, was onboard the Shuttle mission STS-107 (Jan. 16–Feb. 1, 2003). During the nightside phase of the orbit, dedicated observations toward the Earth’s limb above areas of active thunderstorms were made in an effort to image transient luminous events (TLEs) from space. This is the first time such calibrated measurements have been obtained from space. A total of 14 TLEs were observed during the 16-day mission. ^{7062) 7063)}

MEIDEX was part of the FREESTAR (Fast Reaction Experiments Enabling Science, Technology, Applications & Research) project, a complex payload flown as a Hitchhiker payload within SSPP (Shuttle Small Payloads Project) of NASA/GSFC (Goddard Space Flight Center).



Figure 1615: Red sprites (right) captured from ESO’s VLT platform (image credit: Petr Horálek, ESO)

– The ISUAL (Imager of Sprites: Upper Atmospheric Lightning) instrument is a joint project of NSPO (Taiwan), UCB (University of California at Berkeley), National Cheng Kung University of Taiwan, and Tohoku University, Japan. ⁷⁰⁶⁴⁾ It is flown on the FormoSat-2 (former ROCSat-2) mission with a launch of May 20, 2004. On 4 July 2004, ISUAL successfully observed the first images of sprites, sprite halo, and elves. -- Based on the

7062) Y. Yair, C. Price, Z. Levin, J. Joseph, A. Devir, B. Ziv, M. Moalem, P. Israelevich, S. Clodman, “Coordinated observations of sprites and other TLEs from the Space Shuttle during the MEIDEX,” URL: <http://luna.tau.ac.il/~peter/MEIDEX/Publications/Paper6/icae2003.pdf>

7063) Yoav Yair, Colin Price, Baruch Ziv, Peter L. Israelevich, Davis D. Sentman, Fernanda T. Sao-Sabbas, Adam D. Devir, Mitsuteru Sato, Craig J. Rodger, Meir Moalem, Eran Greenberg, Ofer Yaron, “Space shuttle observation of an unusual transient atmospheric emission,” *Geophysical Research Letters*, Vol. 32, 2005, L02801, doi:10.1029/2004GL021551, URL: <http://wwwln.net/publications/yair.grl.2005.pdf>

7064) Rue – Ron Hsu, Alfred B. Chen, Cheng-Ling Kuo, Han-Tzong Su, Harald Frey, Stephen Mende, Yukihiro Takahashi, Lou-Chung Lee, “On the Global Occurrence and Impacts of Transient Luminous Events (TLEs),” AIP (American Institute of Physics) Proceedings of the Workshop: ‘Coupling of Thunderstorms and Lightning Discharges to Near-Earth Space,’ April 17, 2009, Vol. 1118, pp. 99–107

first 4 years of ISUAL observations, Elves are found to be the most abundant type (~80%) of TLEs, whereas sprites and halos only combine to account for ~20%.

– The SpriteSat microsatellite mission of Tohoku University of Sendai (Miyagi Prefecture), Japan is dedicated to monitor sprites in the upper atmosphere (launch on Jan. 23, 2009).

– Feb. 3, 2015: At the ESO's observatories located high in the Atacama Desert of Chile, amazing images of distant objects in the Universe are captured on a regular basis. But in January 2015 (Figure 1615), ESO photo ambassador Petr Horálek captured some amazing photos of much closer phenomena: red sprites flashing in the atmosphere high above distant thunderstorms.⁷⁰⁶⁵⁾

Transducer. A device changing one form of signal energy into another, such as a microphone, a thermocouple, a photocell, etc.

Transistor: A transistor is a basic electrical component, a solid-state electronic device, that alters the flow of electrical current. Transistors are the building blocks of integrated circuits, such as computer processors, or CPUs. Modern CPUs contain millions of individual transistors that are microscopic in size.

Most transistors include three connection points, or terminals, which can connect to other transistors or electrical components. By modifying the current between the first and second terminals, the current between the second and third terminals is changed. This allows a transistor to act as a switch, which can turn a signal on or off. Since computers operate in binary, and a transistor's "on" or "off" state can represent a 1 or 0, transistors are suitable for performing mathematical calculations. A series of transistors may also be used as a logic gate when performing logical operations.

While early transistors were large enough to hold in your hand, modern transistors are so small they cannot be seen with the naked eye. In fact, CPU transistors, such as those used in Intel's Ivy Bridge processor, are separated by a distance of 22 nm. This microscopic size allows chip manufacturers to fit hundreds of millions of transistors into a single processor.

Transmittance (transmissivity). The ratio of power transmitted through a layer of a medium to the power incident upon it.

Transmitter. An electronic device consisting of an oscillator, modulator and other circuits which produce a wave signal for radiation by an antenna.

Transponder. A combined receiver and transmitter system (usually part of a communications system of a satellite) whose function is to transmit signals automatically when triggered by an interrogating signal. In general there are two types of transponders:

- Bent-pipe transponder. This is a simple repeater: it receives an uplink signal at a particular frequency, changes the frequency to one suitable for the downlink, amplifies it to provide it with the required power, and rebroadcasts it to the ground.
- Regenerative repeater.⁷⁰⁶⁶⁾ A regenerative repeater yields improved performance over a quasilinear repeater. It performs the receiving and transmitting function in the same manner as the quasilinear repeater but the regenerative repeater "... contains in each transmission link a demodulator that demodulates the uplink signal to the digital baseband signal and a modulator that remodulates that signal on a downlink carrier. The demodulated signal is retimed and restored to standard form. This approach effectively isolates the uplink performance from the downlink performance, preventing the accumulation of noise and distortion over the two links."

⁷⁰⁶⁵⁾ Jason Major, "Rare Images of Red Sprites Captured at ESO," Universe Today, Feb. 3, 2015, URL: <http://www.universetoday.com/118745/rare-images-of-red-sprites-captured-at-eso/>

⁷⁰⁶⁶⁾ W. L. Pritchard, J. A. Sciulli, "Satellite Communications Systems Engineering," Prentice-Hall Inc., Englewood Cliffs, NJ, 1986, p. 285

Traveling wave tube. A microwave power generating tube that accelerates electrons by varying a magnetic field between cathode and anode to set up waves of electron density.

Tropical year. The interval of time between two successive vernal equinoxes. It is equal to 365.242 mean solar days.

Tropopause. Boundary between the upper troposphere and the lower stratosphere that varies in altitude between approximately 8 km at the poles and 18 km at the equator. The temperature gradient of the tropopause goes to zero (a relative temperature minima exists).

Troposphere. Lowest atmospheric layer, between the surface and the tropopause (lowest 8–15 km of the atmosphere, depending on latitude). The troposphere is characterized by decreasing temperature with height, large vertical motion, and large water vapor content. This is the region where most of the ‘weather’ occurs.

Uncooled thermal imaging detector. Refers to a class of detector arrays that operate at or near ambient (room) temperature. The term “uncooled” is used to distinguish this technology from the historical norm, which is to use detectors that only operate at cryogenic temperatures, e.g. the temperature of liquid nitrogen (77 K) or lower. Two basic uncooled detector types have emerged, ferroelectric detectors and microbolometers. Ferroelectrics have been developed by Texas Instruments and GEC Marconi; microbolometer technology has been developed by Honeywell. Ferroelectric detector technology takes advantage of a ferroelectric phase transition in certain dielectric materials. At and near this phase transition, the electric polarization of the dielectric is a strong function of temperature; small fluctuations of temperature in the material cause large changes in polarization.

If the sensor is maintained at a temperature near the ferroelectric phase transition and if the optical signal is modulated (with a synchronous chopper), then, an infrared image can be readout that reflects the scene temperatures. Microbolometer arrays, on the other hand, consist of detectors made from materials whose electrical resistivity changes with temperature. Each detector is part of a readout circuit that measures the resistance of the element as a signal.

The advantage of uncooled systems is system lifetime and cost (cooled sensor systems need to be chilled, often to cryogenic temperatures, which requires the use of an expensive and highly intricate mechanical cryogenic system).

Universe: What is the Universe? That is one immensely loaded question! No matter what angle one took to answer that question, one could spend years answering that question and still barely scratch the surface. In terms of time and space, it is unfathomably large (and possibly even infinite) and incredibly old by human standards. Describing it in detail is therefore a monumental task. But we here at Universe Today are determined to try!⁷⁰⁶⁷⁾

So what is the Universe? Well, the short answer is that it is the sum total of all existence. It is the entirety of time, space, matter and energy that began expanding some 13.8 billion years ago and has continued to expand ever since. No one is entirely certain how extensive the Universe truly is, and no one is entirely sure how it will all end. But ongoing research and study has taught us a great deal in the course of human history.

Definition: The term “the Universe” is derived from the Latin word “universum”, which was used by Roman statesman Cicero and later Roman authors to refer to the world and the cosmos as they knew it. This consisted of the Earth and all living creatures that dwelt therein, as well as the Moon, the Sun, the then-known planets (Mercury, Venus, Mars, Jupiter, Saturn) and the stars.

⁷⁰⁶⁷⁾ Matt Williams, “The Universe,” Universe Today, 10 May 2017, URL: <https://www.universetoday.com/36425/what-is-the-universe-3/>

The term “cosmos” is often used interchangeably with the Universe. It is derived from the Greek word kosmos, which literally means “the world”. Other words commonly used to define the entirety of existence include “Nature” (derived from the Germanic word natur) and the English word “everything”, whose use can be seen in scientific terminology – i.e. “Theory Of Everything” (TOE).

Today, this term is often used to refer to all things that exist within the known Universe – the Solar System, the Milky Way, and all known galaxies and superstructures. In the context of modern science, astronomy and astrophysics, it also refers to all spacetime, all forms of energy (i.e. electromagnetic radiation and matter) and the physical laws that bind them.

Origin of the Universe: The current scientific consensus is that the Universe expanded from a point of super high matter and energy density roughly 13.8 billion years ago. This theory, known as the Big Bang Theory, is not the only cosmological model for explaining the origins of the Universe and its evolution – for example, there is the Steady State Theory or the Oscillating Universe Theory.

It is, however, the most widely-accepted and popular. This is due to the fact that the Big Bang theory alone is able to explain the origin of all known matter, the laws of physics, and the large scale structure of the Universe. It also accounts for the expansion of the Universe, the existence of the Cosmic Microwave Background, and a broad range of other phenomena.

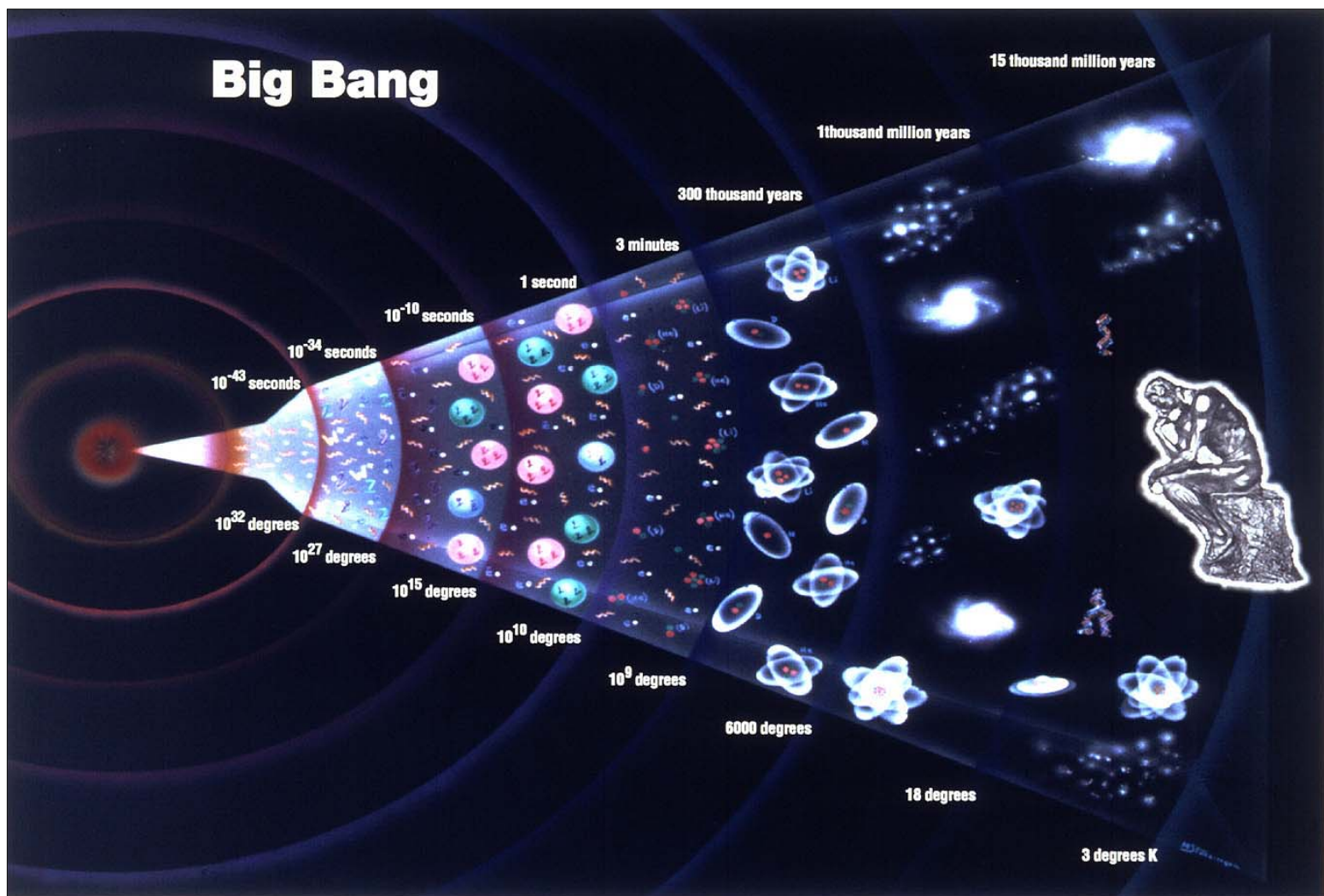


Figure 1616: The Big Bang Theory: A history of the Universe starting from a singularity and expanding ever since (image credit: grandunificationtheory.com)

Working backwards from the current state of the Universe, scientists have theorized that it must have originated at a single point of infinite density and finite time that began to expand. After the initial expansion, the theory maintains that Universe cooled sufficiently to allow for the formation of subatomic particles, and later simple atoms. Giant clouds of these primordial elements later coalesced through gravity to form stars and galaxies.

This all began roughly 13.8 billion years ago, and is thus considered to be the age of the Universe. Through the testing of theoretical principles, experiments involving particle accelerators and high-energy states, and astronomical studies that have observed the deep Universe, scientists have constructed a timeline of events that began with the Big Bang and has led to the current state of cosmic evolution.

However, the earliest times of the Universe – lasting from approximately 10^{-43} to 10^{-11} seconds after the Big Bang – are the subject of extensive speculation. Given that the laws of physics as we know them could not have existed at this time, it is difficult to fathom how the Universe could have been governed. What's more, experiments that can create the kinds of energies involved are in their infancy.

Still, many theories prevail as to what took place in this initial instant in time, many of which are compatible. In accordance with many of these theories, the instant following the Big Bang can be broken down into the following time periods: the Singularity Epoch, the Inflation Epoch, and the Cooling Epoch.

Also known as the Planck Epoch (or Planck Era), the Singularity Epoch was the earliest known period of the Universe. At this time, all matter was condensed on a single point of infinite density and extreme heat. During this period, it is believed that the quantum effects of gravity dominated physical interactions and that no other physical forces were of equal strength to gravitation.

This Planck period of time extends from point 0 to approximately 10^{-43} seconds, and is so named because it can only be measured in Planck time. Due to the extreme heat and density of matter, the state of the Universe was highly unstable. It thus began to expand and cool, leading to the manifestation of the fundamental forces of physics. From approximately 10^{-43} second and 10^{-36} , the Universe began to cross transition temperatures.

It is here that the fundamental forces that govern the Universe are believed to have begun separating from each other. The first step in this was the force of gravitation separating from gauge forces, which account for strong and weak nuclear forces and electromagnetism. Then, from 10^{-36} to 10^{-32} seconds after the Big Bang, the temperature of the Universe was low enough (10^{28} K) that electromagnetism and weak nuclear force were able to separate as well.

With the creation of the first fundamental forces of the Universe, the Inflation Epoch began, lasting from 10^{-32} seconds in Planck time to an unknown point. Most cosmological models suggest that the Universe at this point was filled homogeneously with a high-energy density, and that the incredibly high temperatures and pressure gave rise to rapid expansion and cooling.

This began at 10^{-37} seconds, where the phase transition that caused for the separation of forces also led to a period where the Universe grew exponentially. It was also at this point in time that baryogenesis occurred, which refers to a hypothetical event where temperatures were so high that the random motions of particles occurred at relativistic speeds.

As a result of this, particle-antiparticle pairs of all kinds were being continuously created and destroyed in collisions, which is believed to have led to the predominance of matter over antimatter in the present Universe. After inflation stopped, the Universe consisted of a quark-gluon plasma, as well as all other elementary particles. From this point onward, the Universe began to cool and matter coalesced and formed.

As the Universe continued to decrease in density and temperature, the Cooling Epoch began. This was characterized by the energy of particles decreasing and phase transitions continuing until the fundamental forces of physics and elementary particles changed into their present form. Since particle energies would have dropped to values that can be obtained by particle physics experiments, this period onward is subject to less speculation.

For example, scientists believe that about 10^{-11} seconds after the Big Bang, particle energies dropped considerably. At about 10^{-6} seconds, quarks and gluons combined to form baryons such as protons and neutrons, and a small excess of quarks over antiquarks led to a small excess of baryons over antibaryons.

Since temperatures were not high enough to create new proton–antiproton pairs (or neutron–antineutron pairs), mass annihilation immediately followed, leaving just one in 10^{10} of the original protons and neutrons and none of their antiparticles. A similar process happened at about 1 second after the Big Bang for electrons and positrons.

After these annihilations, the remaining protons, neutrons and electrons were no longer moving relativistically and the energy density of the Universe was dominated by photons – and to a lesser extent, neutrinos. A few minutes into the expansion, the period known as Big Bang nucleosynthesis also began.

Thanks to temperatures dropping to 1 billion kelvin (10^9 K) and energy densities dropping to about the equivalent of air, neutrons and protons began to combine to form the Universe's first deuterium (a stable isotope of hydrogen) and helium atoms. However, most of the Universe's protons remained uncombined as hydrogen nuclei.

After about 379,000 years, electrons combined with these nuclei to form atoms (again, mostly hydrogen), while the radiation decoupled from matter and continued to expand through space, largely unimpeded. This radiation is now known to be what constitutes the Cosmic Microwave Background (CMB), which today is the oldest light in the Universe.

As the CMB expanded, it gradually lost density and energy, and is currently estimated to have a temperature of 2.7260 ± 0.0013 K (-270.424 °C/ -454.763 °F) and an energy density of 0.25 eV/cm³ (or 4.005×10^{-14} J/m³; 400–500 photons/cm³). The CMB can be seen in all directions at a distance of roughly 13.8 billion light years, but estimates of its actual distance place it at about 46 billion light years from the center of the Universe.

Evolution of the Universe: Over the course of the several billion years that followed, the slightly denser regions of the Universe's matter (which was almost uniformly distributed) began to become gravitationally attracted to each other. They therefore grew even denser, forming gas clouds, stars, galaxies, and the other astronomical structures that we regularly observe today.

This is what is known as the Structure Epoch, since it was during this time that the modern Universe began to take shape. This consisted of visible matter distributed in structures of various sizes (i.e. stars and planets to galaxies, galaxy clusters, and super clusters) where matter is concentrated, and which are separated by enormous gulfs containing few galaxies.

The details of this process depend on the amount and type of matter in the Universe. Cold dark matter, warm dark matter, hot dark matter, and baryonic matter are the four suggested types. However, the Lambda–Cold Dark Matter model (Lambda–CDM), in which the dark matter particles moved slowly compared to the speed of light, is the considered to be the standard model of Big Bang cosmology, as it best fits the available data.

In this model, cold dark matter is estimated to make up about 23% of the matter/energy of the Universe, while baryonic matter makes up about 4.6%. The Lambda refers to the Cosmological Constant, a theory originally proposed by Albert Einstein that attempted to show that the balance of mass–energy in the Universe remains static.

In this case, it is associated with dark energy, which served to accelerate the expansion of the Universe and keep its large-scale structure largely uniform. The existence of dark energy is based on multiple lines of evidence, all of which indicate that the Universe is permeated by it. Based on observations, it is estimated that 73% of the Universe is made up of this energy.

During the earliest phases of the Universe, when all of the baryonic matter was more closely space together, gravity predominated. However, after billions of years of expansion, the growing abundance of dark energy led it to begin dominating interactions between galaxies. This triggered an acceleration, which is known as the Cosmic Acceleration Epoch.

When this period began is subject to debate, but it is estimated to have began roughly 8.8 billion years after the Big Bang (5 billion years ago). Cosmologists rely on both quantum mechanics and Einstein's General Relativity to describe the process of cosmic evolution that took place during this period and any time after the Inflationary Epoch.

Through a rigorous process of observations and modeling, scientists have determined that this evolutionary period does accord with Einstein's field equations, though the true nature of dark energy remains illusive. What's more, there are no well-supported models that are capable of determining what took place in the Universe prior to the period predating 10^{-15} seconds after the Big Bang.

However, ongoing experiments using CERN's Large Hadron Collider (LHC) seek to recreate the energy conditions that would have existed during the Big Bang, which is also expected to reveal physics that go beyond the realm of the Standard Model.

Any breakthroughs in this area will likely lead to a unified theory of quantum gravitation, where scientists will finally be able to understand how gravity interacts with the three other fundamental forces of the physics – electromagnetism, weak nuclear force and strong nuclear force. This, in turn, will also help us to understand what truly happened during the earliest epochs of the Universe.

Structure of the Universe: The actual size, shape and large-scale structure of the Universe has been the subject of ongoing research. Whereas the oldest light in the Universe that can be observed is 13.8 billion light years away (the CMB), this is not the actual extent of the Universe. Given that the Universe has been in a state of expansion for billions of years, and at velocities that exceed the speed of light, the actual boundary extends far beyond what we can see.

Our current cosmological models indicate that the Universe measures some 91 billion light years (28 billion parsecs) in diameter. In other words, the observable Universe extends outwards from our Solar System to a distance of roughly 46 billion light years in all directions. However, given that the edge of the Universe is not observable, it is not yet clear whether the Universe actually has an edge. For all we know, it goes on forever!

Within the observable Universe, matter is distributed in a highly structured fashion. Within galaxies, this consists of large concentrations – i.e. planets, stars, and nebulas – interspersed with large areas of empty space (i.e. interplanetary space and the interstellar medium).

Things are much the same at larger scales, with galaxies being separated by volumes of space filled with gas and dust. At the largest scale, where galaxy clusters and superclusters exist, you have a wispy network of large-scale structures consisting of dense filaments of matter and gigantic cosmic voids.

In terms of its shape, spacetime may exist in one of three possible configurations – positively-curved, negatively-curved and flat. These possibilities are based on the existence of at least four dimensions of space-time (an x-coordinate, a y-coordinate, a z-coordinate, and time), and depend upon the nature of cosmic expansion and whether or not the Universe is finite or infinite.

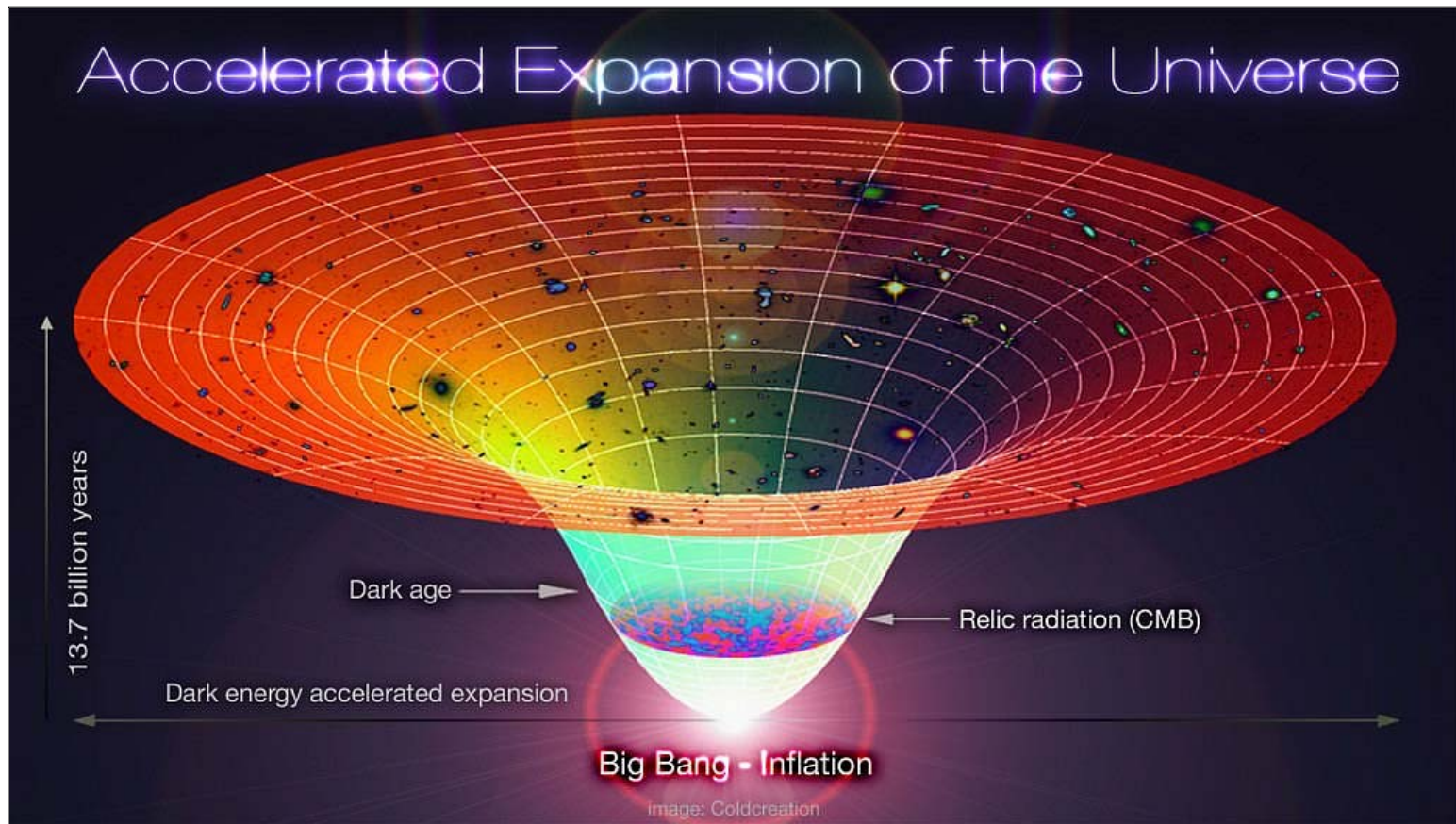


Figure 1617: Diagram showing the Lambda–CBR Universe, from the Big Bang to the the current era (image credit: Alex Mittelmann/Coldcreation)

A positively–curved (or closed) Universe would resemble a four–dimensional sphere that would be finite in space and with no discernible edge. A negatively–curved (or open) Universe would look like a four–dimensional “saddle” and would have no boundaries in space or time.

In the former scenario, the Universe would have to stop expanding due to an overabundance of energy. In the latter, it would contain too little energy to ever stop expanding. In the third and final scenario – a flat Universe – a critical amount of energy would exist and its expansion would only halt after an infinite amount of time.

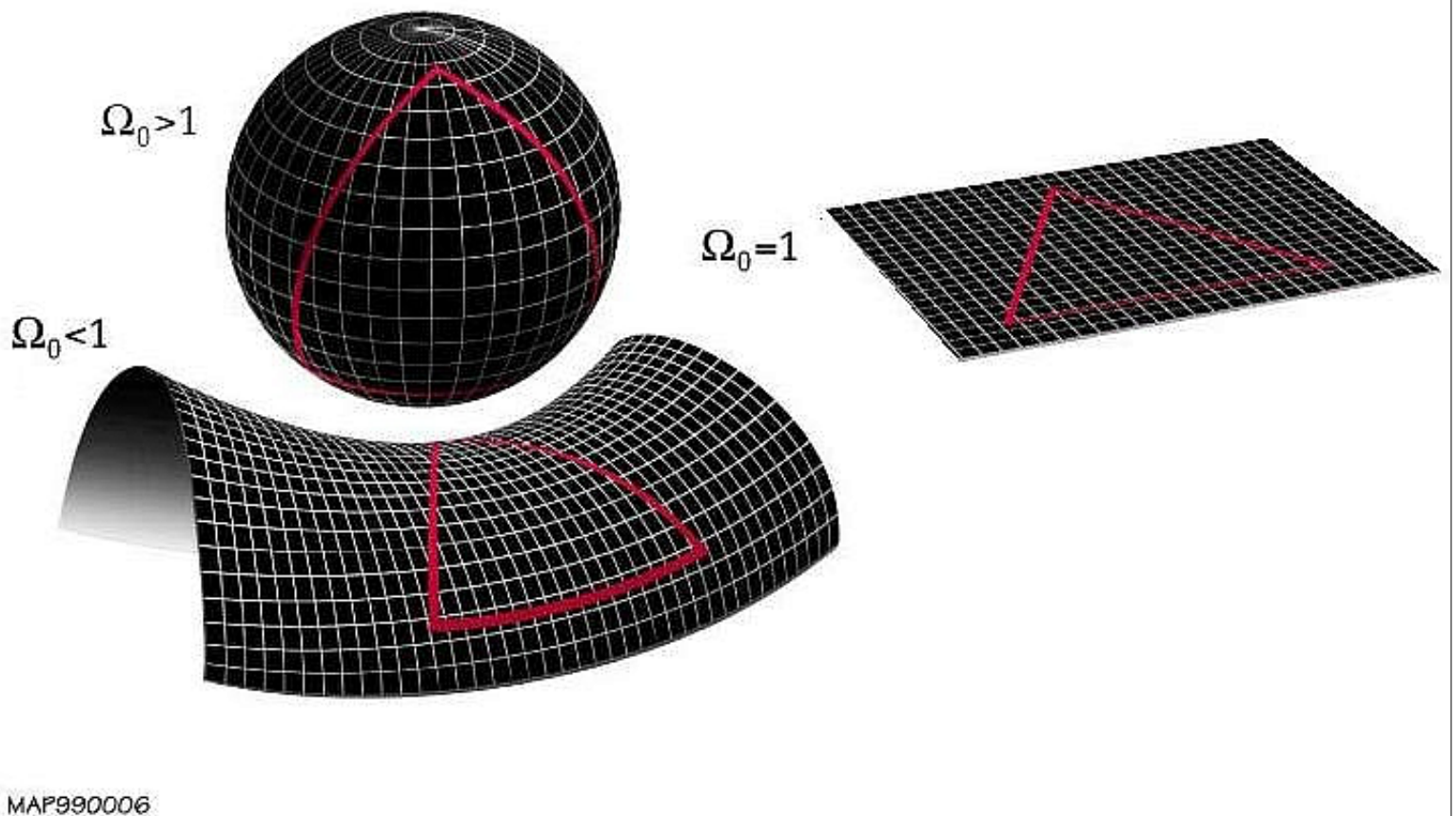


Figure 1618: Various possible shapes of the observable Universe – where mass/energy density is too high; too low – or just right, so that Euclidean geometry where the three angles of a triangle do add up to 180 degrees (image credit: Wikipedia Commons)

Uplink. Refers to the communication path direction from a ground station to a satellite. The information in this uplink is usually used for commanding of a subsystem (in general there are also uplinks in tracking systems, etc). In very elaborate communication systems with intermediate geostationary transmission satellites, the term ‘uplink’ is usually replaced by ‘forward link’ to avoid confusion.

Upwelling. The vertical motion of water in the ocean by which subsurface water of lower temperature and greater density moves toward the surface of the ocean. Upwelling occurs most commonly along the western coastlines of continents, but may occur anywhere in the ocean. Upwelling results when winds blowing nearly parallel to a continental coastline transport the light surface water away from the coast. Subsurface water of greater density and lower temperature replaces the surface water, and exerts a considerable influence on the weather of coastal regions. Carbon dioxide is transferred to the atmosphere in regions of upwelling. This is especially important in the Pacific equatorial regions, where 1 to 2 gigatons of carbon per year may be released to the atmosphere. Upwelling also results in increased ocean productivity by transporting nutrient-rich waters to the surface layer of the ocean. – The term ‘upwelling’ is also used in the context of ‘upwelling radiation.’ This refers to radiation (from the Earth’s surface and from the atmosphere) observed from an airborne or spaceborne sensor.

UTM (Universal Transverse Mercator Projection). A widely used map projection which employs a series of identical projections around the world in the mid-latitude areas, each spanning six degrees of longitude and oriented to a meridian. The UTM projection preserves angular relationships and scale, it easily allows a rectangular grid to be superimposed on it.

UWB (Ultra Wideband) is a radar technology designation. It has been widely employed previously for radar applications such as target identification, SAR for imaging through-foilage, GPR (Ground Penetrating Radar), and others. By definition, any transmission in which the occupied bandwidth is 25% of the carrier frequency, or with bandwidths in excess of 500 MHz, is termed as UWB (Ultra Wideband). UWB has also been referred to as a "carrier free" or "baseband" technology as the pulses can be radiated without a carrier, and transmitted directly to the antenna without any frequency conversion. Among others, UWB has some unique advantages compared to the traditional narrowband systems, i.e. large instantaneous bandwidth enables fine time resolution for network time distribution, precision location capability, or use as radar, it is relatively immune to the multipath effects that narrowband systems suffer because of the short duration of transmitted pulses.⁷⁰⁶⁸⁾

UWB radar works quite differently from the continuous scan radars. Instead of continuously emitting energy and always decoding the returned signal, UWB radars emit extremely fast pulsed signals, or short duration radio signals bursts. UWB radar calculates the returned signal power based on sampling the detector over time. This is called discrete time radio technology. – The UWB radars can provide an image of the target and can identify it, unlike the conventional radars that can only detect and provide coordinates. Enhancing these features for radar requires an essential increase in the radar frequency band and, as a result, new approaches both in radar methods, signal processing algorithms and technologies. The increment of the frequency bandwidth is directly due to the narrower pulse duration, and increase the radar space resolution.

Van Allen Belt. Regions or belts in the Earth's magnetosphere (at about 1.4–1.5 R_E and 4.5–6 R_E) where many energetically charged particles from the solar wind are trapped in the Earth's magnetic field.

Vegetation index. A mathematical algorithm of reflection values (reflectances, digital pixel values) in different spectral bands, used to estimate vegetation characteristics. Such an algorithm also serves to correct undesirable influences, such as differences of soil reflectance, atmospheric influences, etc. – In physical terms vegetation indices are radiometric measures of vegetation usually involving a ratio and/or linear combination of the red and NIR regions. Vegetation indices serve as indicators of relative growth and/or vigor of green vegetation, and are used as intermediaries in the assessment of various plant biophysical parameters, such as leaf area index, percent green cover, green biomass, and fractional absorbed photosynthetically active radiation (FPAR).

The spectral vegetation index concept and its universal generality has its roots in Landsat data interpretation.⁷⁰⁶⁹⁾ As a consequence there are now a multitude of defined spectral vegetation and soil indices in existence. They are all derived, at least in part, by considering the contrast between visible (VIS) and near-infrared (NIR) spectral reflectance from land surfaces. For typical broadband VIS/NIR measurements, green vegetation foliage produces stepped reflectance, with low VIS and high NIR reflectance, a result of pigment absorption in the VIS region and strong light scatter from cell walls in NIR.

Vernal equinox. The point of intersection between the ecliptic and the celestial equator, where the sun crosses from the south to the north (it is in fact the ascending node of the sun's orbit). The vernal equinox marks the beginning of spring for the northern hemisphere.

On the equinoxes the Sun shines directly on the equator and the length of day and night is nearly equal – but not quite. The March equinox marks the moment the Sun crosses the celestial equator – the imaginary line in the sky above the Earth's equator – from south to north and vice versa in September.

7068) A. Alvarez, J.–L. Garcia, M. Lobeira, "UWB techniques in Radar," Proceedings of IRSI (International Radar Symposium India), Bangalore, India, Dec. 20–22, 2005

7069) S. N. Goward, D. L. Williams, "Landsat and Earth Systems Science: Development of Terrestrial Monitoring," PE&RS, July 1997, pp. 887–900

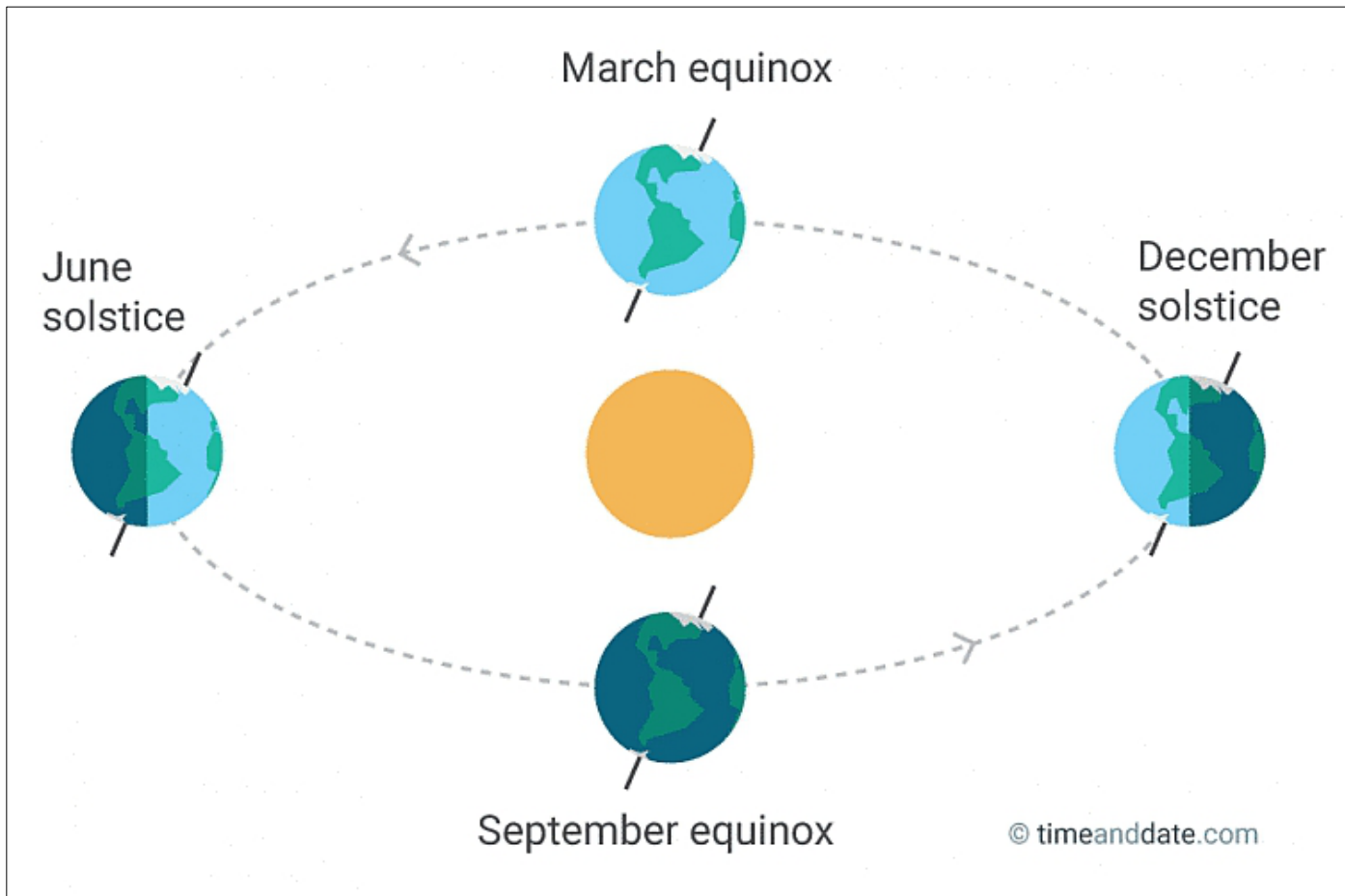


Figure 1619: The Vernal (Spring) Equinox in the Northern Hemisphere is the Autumnal (Fall) Equinox in the Southern Hemisphere and vice versa.

Very Long Baseline Interferometry (VLBI) see Q.9.2. In radio astronomy, the use of a system of two or more antennas placed several hundred or even several thousand kilometers apart, which are operated together as an interferometer. The VLBI measurement technique of enlarged aperture size is used to **improve angular resolution** of the system. The technique allows determination of angular position for distant radio sources by measuring the geometric time delay between received radio signals at two geographically separated stations. The observed time delay is a function of the known baseline vector joining the two radio antennas and the direction to the radio source.

VLBI techniques are also employed in the field of Solid Earth Physics (geodynamics) for determining plate motions with accuracies of better than 1 cm/year. VLBI systems offer a superb tie to an inertial celestial reference frame based on extragalactic radio sources, which in turn is used to maintain the terrestrial reference frame.

Another important application of the VLBI technique is in spacecraft navigation of deep space missions where the measurements at two widely separated ground stations of the phases of tones emitted from a spacecraft are differenced and compared against similarly differenced phase measurements of angularly nearby quasar radio signals. This application of VLBI is known as Delta Differential One-Way Ranging ("**delta-DOR**" or simply as "**ΔDOR**").

The interferometric Δ DOR technique uses a quasar of known celestial coordinates to synchronize clocks at two ground antennas and a phase delay measurement of the spacecraft signal to infer its angular position in the plane containing the baseline vector. By combining observations from multiple baselines (at least three ground antennas), one could measure the spacecraft celestial coordinates to an accuracy of 10 nano radians or less. Being almost

independent from the dynamic model and a time-localized measurement, Δ DOR is a valuable observable quantity for spacecraft navigation in the interplanetary cruise phase, where gravity gradients are small and single dish Doppler and range measurements are less effective in providing a good determination of the state vector. ^{7070) 7071) 7072)}

The advantages of using Δ DOR measurements in favor of the conventional “long arcs of line-of-sight Doppler and ranging data technique” include:

- Δ DOR provides improved angular accuracy by direct geometric measurement of the plane-of-sky position of a spacecraft in the inertial reference frame defined by the quasars
- Orbit solutions based on line-of-sight and Δ DOR data show less sensitivity to system errors, as compared to orbit solutions based on only line-of-sight measurements, due to the cancellation of errors by differencing
- Solutions which incorporate Δ DOR do not have singularities at low geocentric declinations or other adverse geometries
- Δ DOR data may be acquired in a listen-only mode; an uplink is not required.

Video. In general used to mean television, or a system used to communicate the television image. Specifically, pertains to the bandwidth and spectrum position of the signal which results from television scanning and which is used to reproduce a picture. Video images do not have the detailed resolution of film, but offer the advantage of immediate processing capability. This is particularly important in time-sensitive applications.

Vidicon. A generic name for a camera tube of normal light sensitivity. It outputs an analog voltage stream corresponding to the intensity of the incoming light.

Viewing angle. See **look angle**.

Water-Based Propulsion (WBP). The technology employs electric power from the solar array to electrolyze water, converting it into hydrogen and oxygen propellant and electrochemically pumping it to a high storage pressure (140 bar). ⁷⁰⁷³⁾ This propellant can either be used to produce thrust (Isp of about 4000 m/s), or can be recombined as a fuel cell (2.5 times the energy density of the best batteries) to generate electrical power. Cold gas from the pressurized tanks can also be used for attitude control thrusters. The electrolysis and fuel cell functions can be performed either by separate dedicated cell stacks, or can be combined in a new technology known as URFC (Unitized Regenerative Fuel Cell). Since the pressurized gasses are produced on-orbit, WBP is totally inert and non-hazardous at launch.

Water vapor. A very important constituent of the atmosphere. Its amount varies widely in space (vertical and horizontal) and time. The troposphere is the domain of water vapor, with about half of all the atmospheric water vapor in a layer below 2 km (only a minute fraction is above the tropopause). Water vapor is the major vehicle of atmospheric energy transport, a regulator of planetary temperatures and of rainfall. – The amount of water vapor in a given air sample may be determined in a number of different ways, involving such concepts as absolute humidity, mixing ratio, dew point, relative humidity, specific humidity, and va-

7070) D. S. Berry, J. S. Border, “CCSDS Concept Paper: Delta-DOR,” August 4, 2005, URL: <http://public.ccsds.org/publications/archive/CP-5060W0-1.1.pdf>

7071) E. Vasallo, G. Boscagli, D. Lee, W. L. Martin, “Delta-DOR and Regenerative Systems: The New CCSDS Frontier in Spacecraft Ranging,” SpaceOps 2006 Conference, Rome Italy, June 19–23, 2006, paper: AIAA 2006-5705

7072) L. Iess, F. Budnik, C. Colamarino, A. Corbelli, M. Di Benedetto, V. Fabbri, A. Graziani, R. Hunt, N. James, M. Lanucara, R. Maddè, M. Marabucci, G. Mariotti, M. Mercolino, P. Racioppa, L. Simone, P. Tortora, M. Westcott, M. Zannoni, “Improving Tracking Systems for Deep Space Navigation,” Proceedings of TTC 2013, 6th International Workshop on Tracking Telemetry and Command Systems for Space Applications, Darmstadt, Germany, Sept. 10–13, 2013

7073) S. R. Wassom, “Revolutionary Propulsion Concepts for Small Satellites,” AIAA/USU Conference on Small Satellites, Logan UT, Aug. 13–14, 2001, SSC01-IX-4

por pressure.

Water vapor plays a crucial role in the dynamics and thermodynamics of many atmospheric processes over a wide range of temporal and spatial scales, covering the global hydrologic and energy cycles that effectively define the local and global climate change.

Water–vapor absorption bands. Wavelength bands where water vapor – free or bound – absorbs radiation to a high degree. Absorption bands in the IR region are near 1.4 μm , 1.8 μm , 2.7 μm , 6.3 μm (strong), 11 μm , and 30 μm .

Wavefront. A three–dimensional surface in space for which the field radiated by the antenna has the same phase at all points. At a large distance R from the antenna, the wavefront is a spherical surface with radius R over the angular window established by the antenna pattern. For most geometries encountered in remote sensing, the wavefront may be approximated by a plane tangent to the spherical surface.

Wavenumber (ν). The number of waves per cm (the reciprocal of the wavelength). $\nu = 1/\lambda$. A wavenumber of 10,000 corresponds to a wavelength (λ) of 10^{-4} cm^{-1} , or to a wavelength (λ) of 1 μm . Conversion of a wavenumber resolution $\Delta\nu$ into a wavelength resolution $\Delta\lambda$:

$$\nu = 1/\lambda \Rightarrow |\Delta\nu| = |\Delta\lambda| / \lambda^2 \Rightarrow |\Delta\lambda| = |\Delta\nu| \lambda^2$$

Example: convert the wavenumber resolution $\Delta\nu = 20 \text{ cm}^{-1}$ into a wavelength resolution for the spectral range of 400–800 nm.

$$|\Delta\lambda| = |\Delta\nu| \lambda^2 = 20 \text{ cm}^{-1} \times (400 \text{ nm})^2 = 2 \times 10^{-6} \text{ nm}^{-1} \times 160000 \text{ nm}^2 = \underline{0.32 \text{ nm}} \text{ for } \lambda = 400 \text{ nm}$$

$$|\Delta\lambda| = |\Delta\nu| \lambda^2 = 20 \text{ cm}^{-1} \times (800 \text{ nm})^2 = 2 \times 10^{-6} \text{ nm}^{-1} \times 640000 \text{ nm}^2 = \underline{1.28 \text{ nm}} \text{ for } \lambda = 800 \text{ nm}$$

In this context belongs also the **spectral resolving power**, which is defined as the following ratio: $\lambda/\Delta\lambda$. Example: find the spectral bandwidth for a spectral range from 1.0 – 2.5 μm when the spectral resolving power ($\lambda/\Delta\lambda$) of the instrument is given as 250.

$$\Delta\lambda = \lambda/250 = 1 \mu\text{m}/250 = 0.004 \mu\text{m} \text{ or } 4 \text{ nm} \text{ at the lower bound of the spectral range}$$

$$\Delta\lambda = \lambda/250 = 2.5 \mu\text{m}/250 = 0.010 \mu\text{m} \text{ or } 10 \text{ nm} \text{ at the upper bound of the spectral range.}$$

Wiener spectrum (after Norbert Wiener, American mathematician, 1894–1964), also referred to as “noise power spectrum.” A measure of how the quantum noise in an imaging system is recorded in the presence of grain noise in the film emulsion. All imaging systems have a modulation transfer function MTF curve that is the result of the systems properties of imaging different spatial frequencies. The MTF curve gradually decreases with higher spatial frequency. As a result, the higher spatial frequency part of the quantum noise is suppressed accordingly. The noise power density (noise in a certain frequency interval) is also called the Wiener spectrum of the image.

Wind shear. The rate of change of the wind velocity components with distance.

Window (electromagnetic). Wavelength or frequency region in which the atmosphere is largely transparent to electromagnetic radiation (e.g. optical window, microwave window, etc.).

Window operation. Processing of the (radiation) values of pixels within a predefined window, mostly limited to one spectral band – also called a ‘filter.’ Examples are convolution filters, variance filters, etc. . The filter output is assigned to the central pixel of the window.

Whiskbroom scanner. A line–scanning optomechanical sensor system.

World Geodetic System 1984 (WGS–84). Refers to a set of parameters established by the US Defense Mapping Agency (DMA) for determining geometric and physical geodetic relationships on a global scale. The system includes a geocentric reference ellipsoid, a coordinate system, and a gravity field model. The ellipsoid is essentially that of the International Union of Geodesy and Geophysics (IUGG) ‘Geodetic Reference System 1980.’ The coordinate system is a realization of the conventional terrestrial system, as established by the International Earth Rotation Service.

WSN (Wireless Sensor Network). Refers to a network technology, where all nodes (either moving or stationary) can both provide and relay data. All nodes are attached to sensor and control devices to enable these devices to wirelessly interconnect to each other. Typically, a WSN consists of many tiny sensor nodes (low–power, and miniature embedded processors, radios, sensors, and actuators, often integrated onto a single chip) that communicate over wireless channels and perform distributed sensing and collaborative data processing. The applications and developments of WSN technology simply abound. The primary function of a WSN is data acquisition or monitoring of some medium or environment.

In the early 21st century, WSN is also a new and promising technology for space exploration that has yet to prove the numerous advantages one can expect: low cost, accurate measurements over a large surface or volume, short setup time of a mission, high reliability through redundancy.

Zenith angle. The angular distance of any celestial object from a given observer’s zenith, measured along the great circle of the celestial sphere from zenith to object.

Zodiacal light. A faint glow that extends away from the sun in the ecliptic plane of the sky, visible to the naked eye in the western sky shortly after sunset or in the eastern sky shortly before sunrise. Its spectrum indicates it to be sunlight scattered by interplanetary dust. The zodiacal light contributes about a third of the total light in the sky on a moonless night.

Zodiacal light is the scattered sunlight from billions upon billions of dust grains, not at the moon, but in the innermost reaches of the solar system. The origin of this dust appears to be comets, which shed gas and dust in their orbital progress around the sun.



Figure 1620: An example of zodiacal light (image credit: Yuri Beletsky, ESO)